GEOLOGICAL SURVEY OF ALABAMA

Donald F. Oltz
State Geologist

Economic Geology Division
W. E. Osborne, Director

Final Annual Report

GEOLOGIC AND ECONOMIC CHARACTERIZATION AND NEAR-TERM POTENTIAL OF SAND RESOURCES OF THE EAST ALABAMA INNER CONTINENTAL SHELF OFFSHORE OF MORGAN PENINSULA, ALABAMA

by

Richard L. Hummell

Prepared by the Geological Survey of Alabama in fulfillment of U.S. Department of the Interior, Minerals Management Service Cooperative Agreement No. 1435-01-98-CA-30935.

Tuscaloosa, Alabama
1999

CONTENTS

Page

ILLUSTRATIONS

TABLES

GEOLOGIC AND ECONOMIC CHARACTERIZATION AND NEAR-TERM POTENTIAL OF SAND RESOURCES OF THE EAST ALABAMA INNER CONTINENTAL SHELF OFFSHORE OF MORGAN PENINSULA, ALABAMA

By

Richard L. Hummell

ABSTRACT

Vibracores and borings collected from the east Alabama inner continental shelf indicate that a Holocene transgressive fluvial-deltaic and marine-fill sequence overlies estuarine and fluvial-deltaic deposits at least partly of Pleistocene age. In addition, the data show that a southward dipping, late Pleistocene-early Holocene disconformity (youngest transgressive surface) was formed by erosion of these estuarine and fluvial-deltaic deposits during late Pleistocene and early Holocene regression and sea-level lowstand. Subsequently, north-south oriented networks of channels of the Perdido and Mobile-Tensaw fluvial-deltaic systems incised into pre-Holocene deposits south of present-day Morgan Peninsula.

Transgressive flooding of the east Alabama inner continental shelf between 10,000 and 6,000 years before present caused marine, fluvial-deltaic, and ebb-tidal delta sediments to be deposited over pre-Holocene estuarine and fluvial-deltaic deposits. With the decrease in the rate of sea level rise about 4,500 years before present, shelf paleochannels were partly backfilled with Holocene fluvial-deltaic sediments. The decrease in the rate of sea level rise, nearshore accumulation of sand from reworked shelf sediments, and the formation of the longshore drift system along the southern margin of Morgan Peninsula fostered late Holocene barrier island development through vertical accretion, initiated and promoted ebb-tidal delta growth through vertical accretion and progradation, and produced a massive inner continental shelf sand sheet

with imbedded shelf sand ridges and transverse bars which completed infilling of paleochannels and buried Holocene fluvial-deltaic deposits.

Lithofacies in the study area include shelf mud, surficial sand sheet, ebb-tidal delta (undifferentiated), delta front, channel sand, peat, marsh, levee, interdistributary bay, and pre-Holocene. The surficial sand sheet lithofacies would provide an excellent source of beach nourishment sand for Morgan Peninsula Gulf of Mexico beaches. Cross sections and isopach maps indicate that variation in surficial sand sheet lithofacies thickness is associated with the presence of the ebb-tidal delta of Mobile Bay, paleochannels, paleochannel divides, shelf sand ridges, and transverse bars. Total estimated volume of surficial sand sheet lithofacies in the study area was calculated to be 1.75 billion cubic yards - 0.56 billion and 1.18 billion cubic yards in state and federal waters, respectively. Alternative sources of beach nourishment sand could be obtained by recovering delta front and channel sand lithofacies.

Hurricane Georges impacted coastal Alabama September 27, 1998, causing extensive damage to the Alabama Gulf of Mexico shoreline. The Geological Survey of Alabama (GSA) surveyed post-storm beach profiles at 29 shoreline monitoring stations. Future resurveys of the beaches should determine the amount of beach eroded by the hurricane, how much beach was put back by nature, and the net loss of beach due to the hurricane.

INTRODUCTION

Hard mineral resources in the Exclusive Economic Zone (EEZ) have been the target of much research in recent years due to a growing need to delineate additional supplies of sand and gravel, shell, heavy minerals, phosphates, and other economic minerals. In 1986, the U.S. Department of the Interior, Minerals Management Service (MMS) established the Gulf Task Force, composed of representatives of Alabama, Mississippi, Louisiana, and Texas, to assess the occurrence and economic potential of hard mineral (nonfuel) resources in the EEZ, offshore Alabama, Mississippi, Louisiana, and Texas based on available data. Sand and gravel, shell, and heavy minerals were the primary hard minerals identified in the Gulf of Mexico EEZ. Sand was identified as the most abundant mineral and as having the highest near-term leasing potential. Based on these results, ensuing studies by the task force have been directed at characterizing high-quality sand deposits for use in beach restoration projects.

Based on the work of Parker (1990), Parker and others (1997) confined their sand resources study to five sites within the Alabama EEZ that were thought to contain beach nourishment-quality sand in the form of shelf sand ridges and shore connected and oblique bars (transverse bars). Their work confirmed the presence of these sand deposits. However, examination of their data during this study and in a previous study (Hummell, 1996) indicate that volumetrically greater sand resources occur in Alabama state and federal waters in the form of a geographically extensive shelf sand sheet (sometimes referred to in the literature as the MAFLA sand sheet). The shelf sand ridges and transverse bars are part of this sand sheet. In addition, the highly detailed stratigraphy of lithofacies and microfacies developed by Parker and others (1997) works reasonably well for Alabama shelf sand ridges and transverse bars, but is not applicable shelf-wide in Alabama as are the stratigraphies of Hummell (1996) and McBride (1997).

The purpose of this study is to map the shelf sand sheet in state and federal waters south of Morgan Peninsula as a potential sand resource for Baldwin County beach nourishment projects (fig. 1). The study area consists of the eastern part of the Alabama inner continental shelf (hereafter collectively referred to as study area) (figs. 1, 2). This area is bordered on the north by the Gulf of Mexico shoreline of Baldwin County. The eastern boundary of the study area is the Alabama-Florida state line and its projection south across the continental shelf (87° 31' 09" west longitude). A north-south line extending offshore from the eastern margin of Main Pass forms the western boundary of the study area (88° 02' 30" longitude). The southern boundary of the study area is 30° 05' 00" north latitude. This study is intended to compliment the west Alabama inner continental shelf work of Hummell (1996) and Dauphin Island sand resource mapping by Hummell and Smith (1995, 1996) and Hummell (1998).

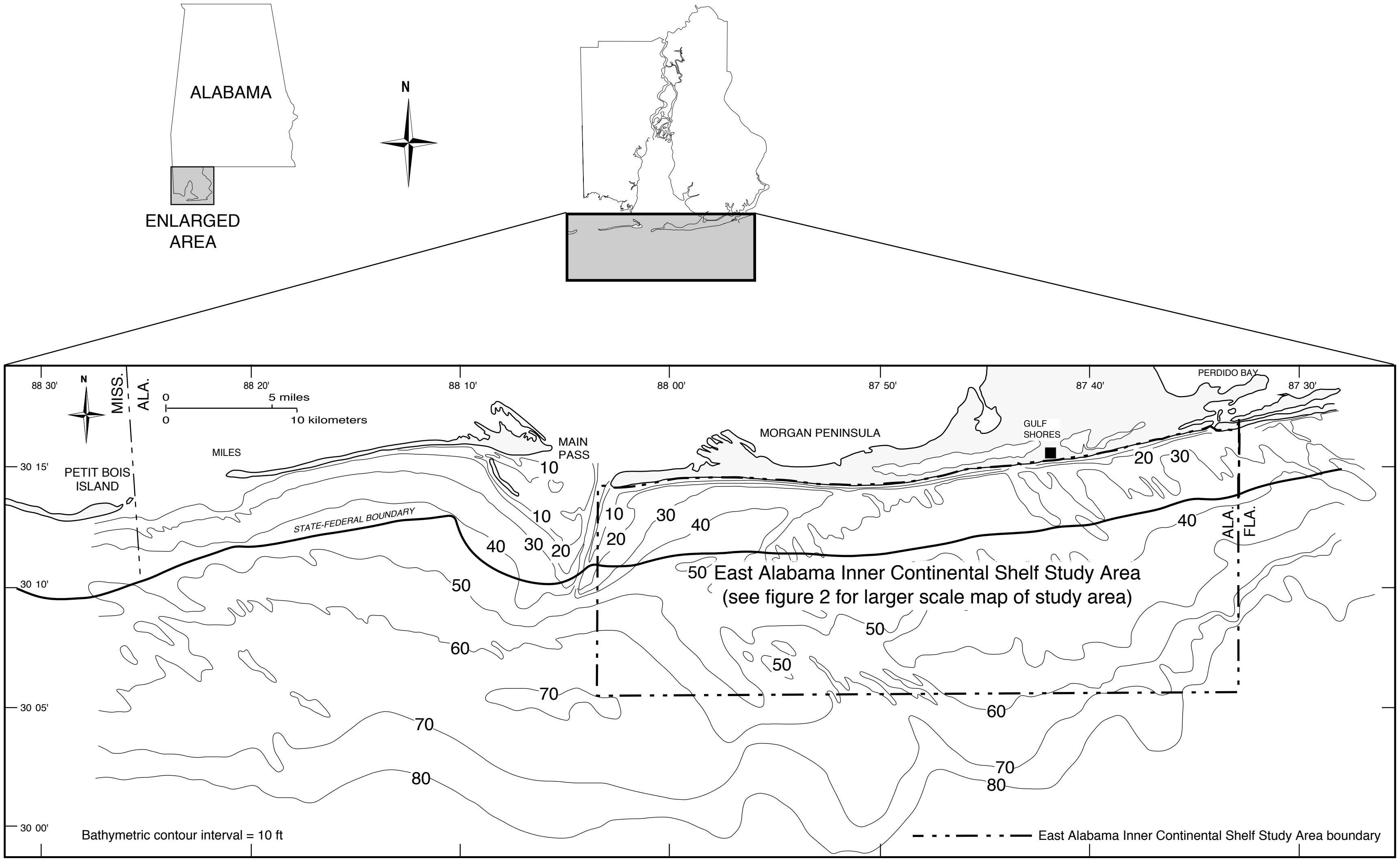


Figure 1.--Map of the Alabama EEZ showing the east Alabama inner continental shelf study area (modified from Parker and others, 1997).

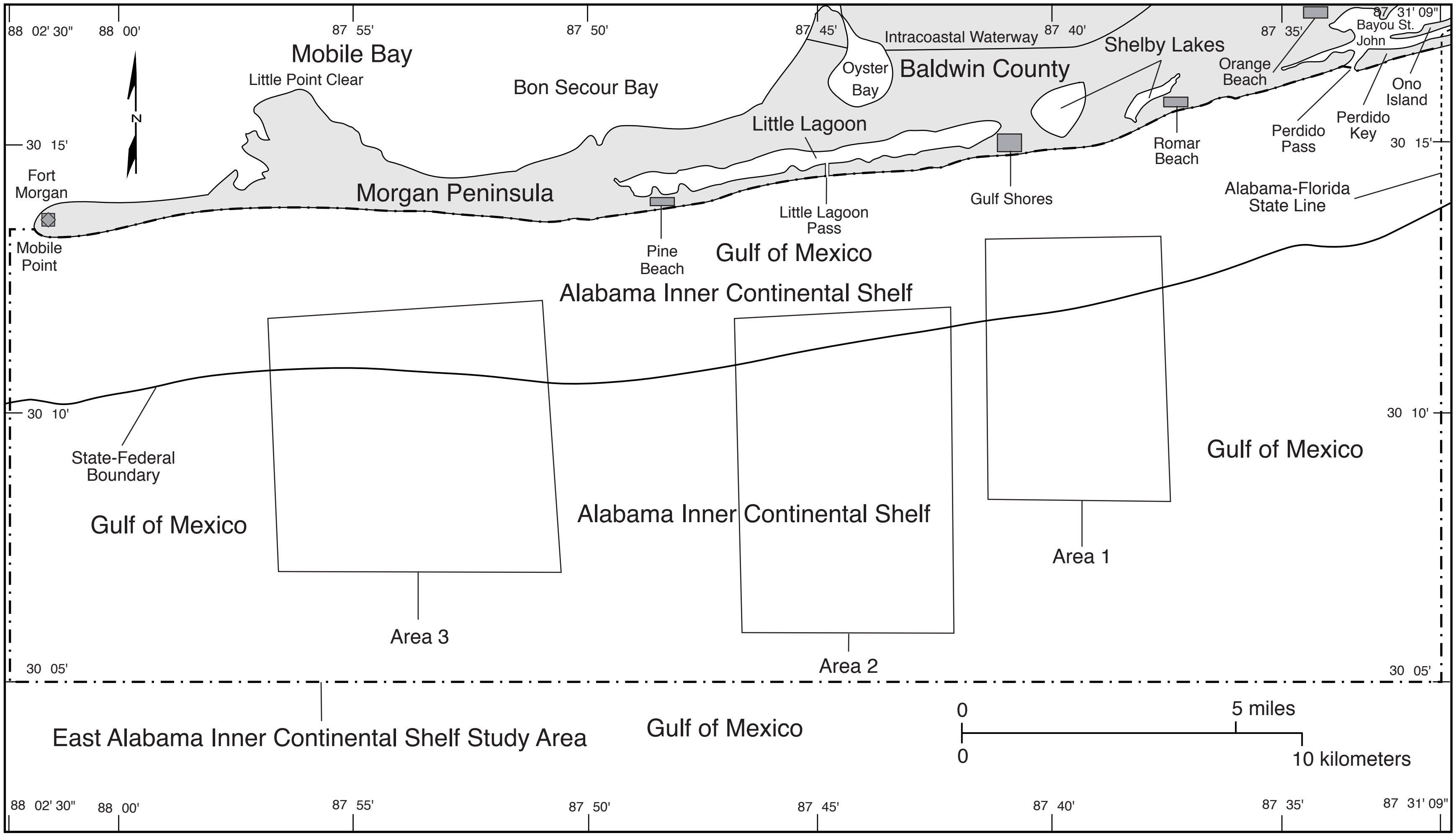


Figure 2.--Map of coastal Alabama showing the east Alabama inner continental shelf study area (see figure 1 for location of map).

ACKNOWLEDGMENTS

I would like to thank the staff of the University of Mississippi Marine Minerals Technology Center, Oxford, Mississippi, and especially the crew of the R/V *Kit Jones*, for assistance with marine vibracoring. Likewise, the field logistical assistance received and permission to use docks for embarkation and disembarkation from Mobil Exploration and Producing U.S., Inc. and the Marine Environmental Sciences Consortium, Dauphin Island Sea Lab, is appreciated. I also thank Henry Moore of the Alabama Oil and Gas Board for assistance with field sampling.

GEOGRAPHIC SETTING

The Alabama coastal area, which includes the southern portions of Mobile and Baldwin Counties, is an area of multiple socioeconomic uses as well as a complex of coastal ecosystems and environments. The area encompasses over 0.9 million acres of open water, 465 miles (mi) of shoreline, and 17,920 acres of coastal marshes fringing the state (Crance, 1971; Christmas, 1973; Alabama Coastal Area Board, 1978). The physiography of the Alabama coastal area is dominated by Mobile Bay and the Mississippi-Alabama continental shelf. The Mobile Bay estuary is a submerged alluvial valley at the terminus of the Mobile-Tensaw River system, the nation's sixth largest river system in total drainage area and first in ratio of area to discharge (Isphording and others, 1985). Morgan Peninsula separates Mobile Bay from the Gulf of Mexico (fig. 2). The Gulf of Mexico shoreline of Baldwin County is densely populated, especially from Pine Beach to Perdido Pass (fig. 2).

Mobile Bay is a bell-shaped estuary that measures 33 mi from the Mobile-Tensaw delta at the northern end of Mobile Bay to Main Pass, the 3-mi wide inlet connecting Mobile Bay to the Gulf of Mexico at the southern end of Mobile Bay (fig. 3). An ebb-tidal delta is located at the mouth of Mobile Bay. The delta measures about 10 mi wide, extends about 6 mi into the Gulf of Mexico, and is submerged to an average depth of about 10 feet (ft). The emergent portion of the ebb-tidal

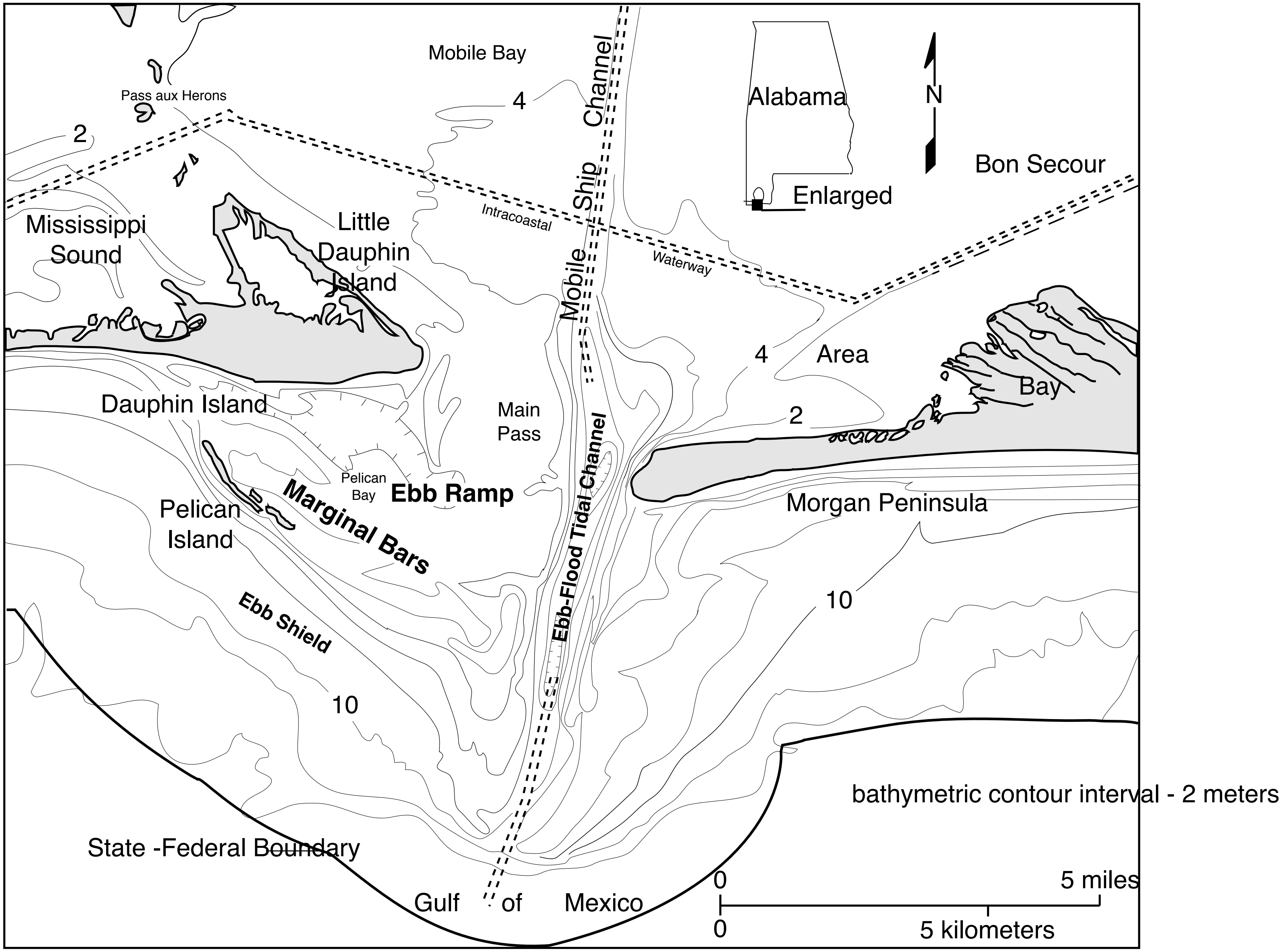


Figure 3.--Geomorphology of the ebb-tidal delta of Mobile Bay (modified from Hummell, 1996).

delta consists of numerous shoals and ephemeral islands. The ebb-flood tidal channel contains the Mobile Ship Channel and the natural tidal channel which has been scoured to depths of 54 to 58 ft by ebb and flood tidal currents (Boone, 1973) (fig. 3). The maximum channel depth is 60 ft west of Mobile Point (U.S. Department of the Navy, 1986). The study area includes that portion of ebb-tidal delta east of the Mobile Ship Channel (fig. 3).

Perdido Bay is connected to the Gulf of Mexico by Perdido Pass (fig. 2). Perdido Bay lies along the eastern boundary between Alabama and Florida and is about 17 mi long and 2 to 4 mi wide along much of its length. Average water depth in the bay is about 8 ft. The Perdido River forms the boundary between Alabama and Florida and flows into the head of Perdido Bay.

The east Louisiana-Mississippi-Alabama Shelf (fig. 4) is a triangular region that includes parts of offshore Louisiana, Mississippi, Alabama and northwest Florida (Parker, 1990). The shelf extends from the Mississippi Delta eastward to DeSoto Canyon and from the southern shorelines of the Mississippi-Alabama-northwest Florida barrier islands to the 650-ft isobath (Parker, 1990). The slope break between the shelf and shoreface here occurs at about the 19.5-foot isobath. The shoreface gradient south of Morgan Peninsula is about 70 feet per mile (ft/mi) and the shelf gradient from the shoreface of Morgan Peninsula to the State-Federal boundary is about 9 ft/mi. The surface within the study area shows relief caused by relict coastal features that survived reworking by marine transgression, lack of fluvial-deltaic sedimentation associated with the Mississippi River system, and Holocene shelf sand ridges and transverse bars (Vittor and Associates, Inc., 1985). Larger scale bathymetric features include the shelf sand sheet and ebb-tidal delta of Mobile Bay (fig. 5). Water depths in the study area range from sea level along its northern boundary to over 80 ft in the southeast corner.

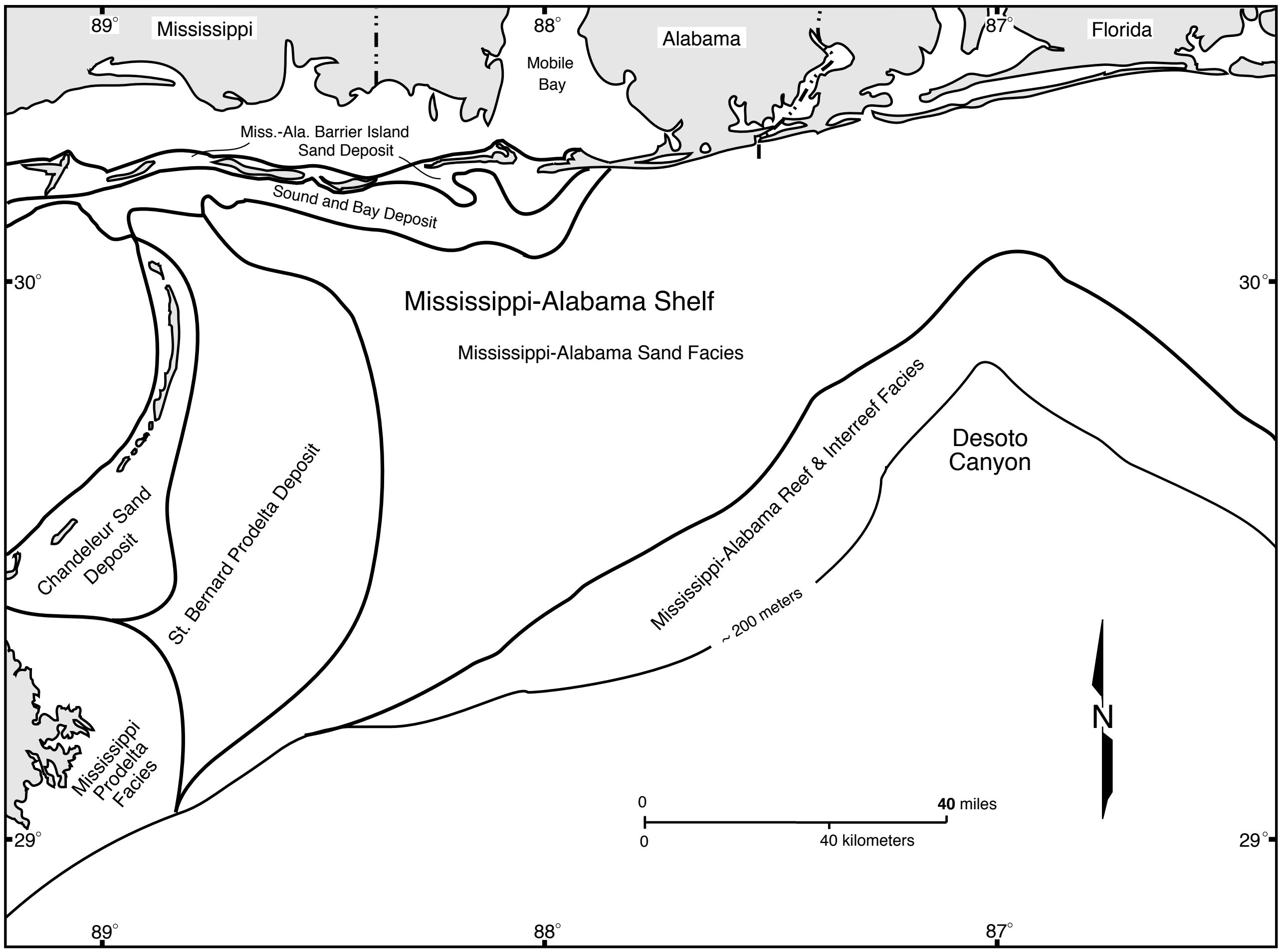


Figure 4.--Sedimentary facies on the Mississippi-Alabama shelf (modified from Ludwick, 1964; Boone, 1973).

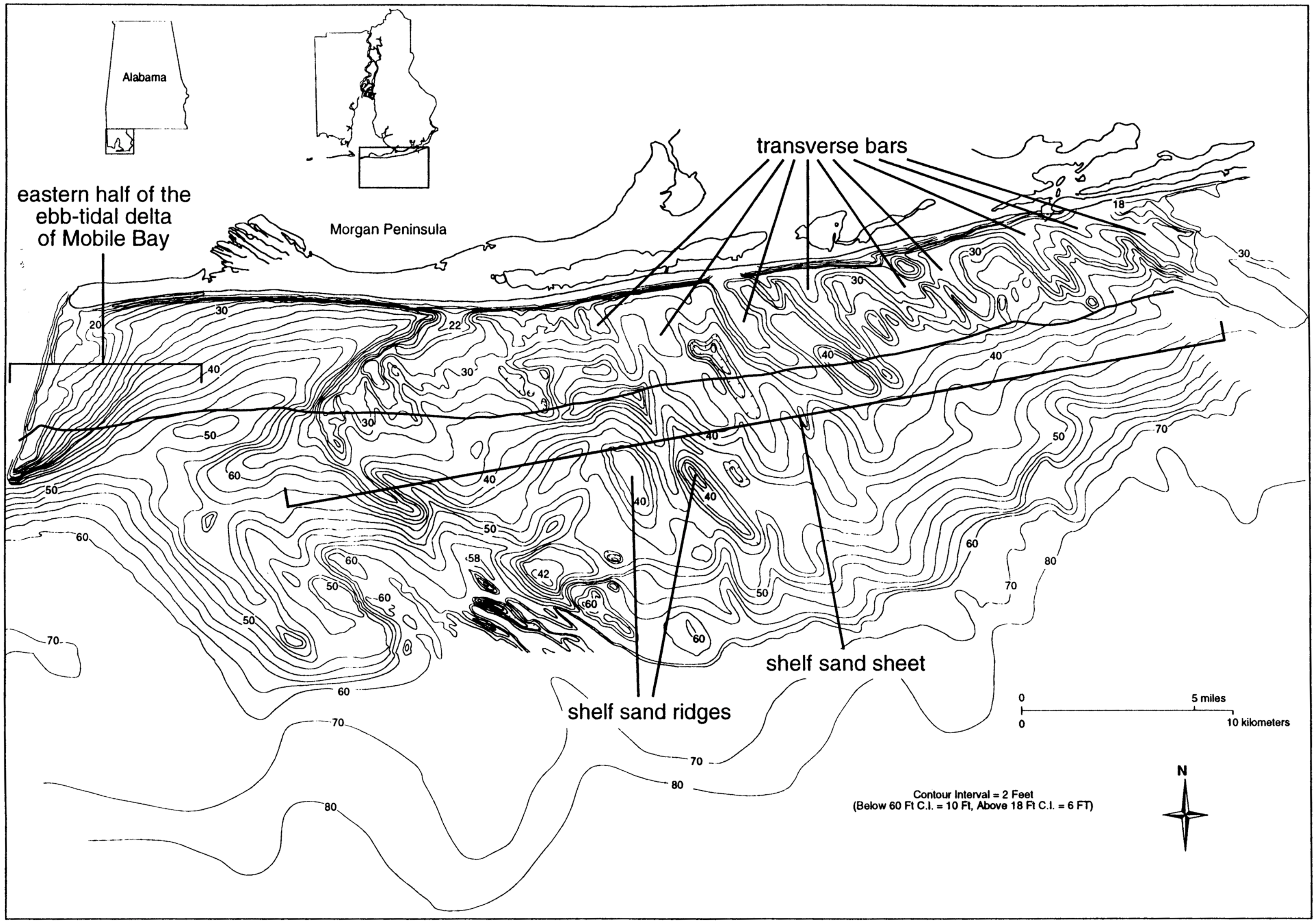


Figure 5.--Bathymetry and major geomorphological features of the east Alabama inner continental shelf (modified from Parker and others, 1997).

CLIMATE AND METEOROLOGY

Coastal Alabama has a humid subtropical climate (Trewartha and Horn, 1980) with an average annual temperature of 68° Fahrenheit (F) and greatest range from a high of 90° F in the summer to 20° F in winter (Vittor and Associates, 1985). Wind and wave activity is low to moderate along the Alabama coast. Prevailing winds average 8 miles per hour (mph) and are stronger and northerly in the winter and calmer and southerly during the summer (Vittor and Associates, 1985). Precipitation in the form of rain occurs throughout the year, but is concentrated during summer months due to thunderstorm and tropical storm activity.

The central Gulf of Mexico coast has one of the highest frequencies of hurricane landfall in the United States. From 1871 through 1980 an average of 2.2 tropical storms made landfall along every 11.5 mi stretch of the coast (Neumann and others, 1981). Tropical storms are capable of producing heavy rainfall over coastal Alabama. Rainfall amounts of 0.4 to 0.8 ft are not unusual.

TIDES

The astronomical tide along coastal Alabama is diurnal, having one high and one low tide per day (U.S. Department of the Navy, 1986). During the biweekly neap tide, however, two highs and two lows occur within one day (U.S. Department of the Navy, 1986). The mean tidal range is 1.2 ft at Mobile Point (Crance, 1971), which is classified as microtidal (Hubbard and others, 1979). Mean low water during the winter months ranges from 0.5 to 1.0 ft below that during the summer months (U.S. Army Corps of Engineers, 1979).

WAVES

Wave intensity along coastal Alabama is low to moderate, with periods ranging from 3 to 8 seconds and wave height rarely over 3 ft (Upshaw and others, 1966). This is consistent with the limited flood-tidal delta development landward of the ebb-tidal delta of Mobile Bay. These fair-weather waves are important for longshore transport of sediments in the nearshore zone (Upshaw and others, 1966). Wave approach is predominantly from the southeast. Intense wave activity associated with hurricanes and other storm events helps rework shelf sediment (Upshaw and others, 1966; Chermock and others, 1974).

Wave heights in the nearshore area generally are proportional to wind speeds, with wave heights at a minimum during the summer and a maximum during the winter (Chermock and others, 1974). Chermock and others (1974) state that wave heights of 12 ft occur sporadically throughout the year, but heights of 20 ft or greater have been reported in February and October only.

WATER TEMPERATURES

Surface water temperature of Gulf of Mexico water seaward of Morgan Peninsula out to about 12 mi offshore reflect fluctuations in air temperatures, ranging from a high of 86° F to a low of 53.6° F (Vittor and Associates, 1985). Gradual warming of surface water throughout the spring and early summer months can lead to temperature stratification during July with generally uniform water temperature profiles during October and November (Vittor and Associates, 1985). In general, water temperature conforms less to air temperature with greater distance from shore and greater depth of the water column (Vittor and Associates, 1985).

SALINITY

Overall, interactions between Mobile Bay, eastern Mississippi Sound, Perdido Bay, and the Gulf of Mexico result in dynamic and constantly changing water movement in the nearshore zone. Salinity of continental shelf water seaward of Dauphin Island is usually highly variable due to low salinity water discharged from Mobile Bay and eastern Mississippi Sound which are mixed with marine water of varying salinity (Vittor and Associates, 1985). Salinity is less variable south of Morgan Peninsula.

Limited data has prevented determination of any seasonal or annual cycle in nearshore Alabama salinity distribution. In general, steep salinity gradients (0 to 36 parts per thousand or ppt) are sometimes observed within a short distance (Vittor and Associates, 1985). Meteorological events (storms and cold air outbreaks) disrupt seasonal patterns of salinity distribution. During late spring and early summer, low salinity surface water may spread over much of the nearshore continental shelf (Vittor and Associates, 1985).

HYDROGRAPHIC SETTING

GENERAL HYDROGRAPHY

Numerous studies have been conducted on circulation patterns within coastal Alabama, especially Mobile Bay, employing direct measurement, remote sensing techniques, and computer modeling. Circulation on the continental shelf of the northern Gulf of Mexico is strongly influenced by four factors: open Gulf circulation (known as the Loop Current), wind, tides, and freshwater discharge from rivers (Vittor and Associates, 1985). Secondary factors include the configuration of the coast, bathymetry, and the Coriolis force.

Sustained winds tend to be the dominant driving force of the circulation on the inner continental shelf (Vittor and Associates, 1985). In the case of an onshore wind in shallow water, surface water tends to flow with the wind direction while bottom water tends to flow offshore following a seaward-directed pressure gradient induced by an elevation of sea level near the coast (Vittor and Associates, 1985). The presence of other forces, such as a horizontal density gradient, will alter this scheme dramatically (Vittor and Associates, 1985). If a horizontal density gradient is present in bottom water, such that the lighter fraction of water lies near the coastline, the density current will oppose and perhaps reverse the effect of an onshore wind on the current field (Vittor and Associates, 1985). Similarly, offshore wind will drive light (and/or low salinity) surface water away from the coast, resulting in the upwelling of heavier bottom water (Vittor and Associates, 1985). The horizontal density gradient that results is confined to the surface layer and directed offshore as a density current (Vittor and Associates, 1985).

Due to their complexity and seasonal variability, currents on the inner continental shelf are not well described (Vittor and Associates, 1985). However, general understanding of the overall patterns can be derived from the works of Schroeder (1976), Chuang and others (1982), Kjerfve (1983), and Kjerfve and Sneed (1984).

Drift bottles released during late spring and early summer from a Stage I platform located 12.4 mi offshore from Panama City, Florida, were found primarily along the northwest Florida beaches (Tolbert and Salsman, 1964). However, the recovery zone shifted westward toward Alabama and Mississippi coasts during late summer and early fall, coinciding with the peak frequency in the westward wind component (Tolbert and Salsman, 1964).

In addition to the tidal current, wind and horizontal density gradients significantly influence current structure on the shelf. A strong onshore wind (that is from the southeast) results in a transient two-layer flow in the cross-shelf direction (vertical circulation patterns with onshore flow in the surface water and offshore flow in the bottom water) (Vittor and Associates, 1985). Subsequent to this onshore wind, strong south to southwesterly setting currents persist, establishing a relatively stable flow pattern (Vittor and Associates, 1985).

The shoreline variation in coastal geometry plays a major role in controlling circulation patterns on the shelf (Murray, 1976; Chuang and others, 1982). Variations in frequency response indicate that circulation is strongly affected by the wind duration, density stratification, and coastal geometry (Chuang and others, 1982). In his studies of the influence of wind on shelf circulation, Schroeder (1976, 1977) shows a very close correlation of bottom flow with the Ekman spiral.

Sustained winds tend to be the dominant driving force of the circulation on the inner continental shelf (Vittor and Associates, 1985). Wind-driven circulation is caused by frictional drag of the air as it passes over the surface of the water (Vittor and Associates, 1985). In deep water far from coasts, surface currents in the Northern Hemisphere are deflected 45° to the right of the wind direction; this deflection continues to rotate clockwise as depth increases, forming the logarithmic Ekman spiral (Vittor and Associates, 1985). In shallow water far from coasts, the same balance of forces produces a deflection to the right, but the angle between wind and surface current is less than 45° (Vittor and Associates, 1985). In water depths of 5 to 10 meters (m) the maximum deflection with depth is 5 to 10° (Vittor and Associates, 1985).

Analysis of current data collected 16.1 mi south of Mobile Bay shows the tendency of near-bottom waters to be transported about 90° to the right of sustained wind direction. During July 1976, prevailing winds were to the north and northeast with near-bottom currents to the east and southeast. During November 1976, prevailing winds were to the south with a prevailing near-bottom current direction to the west. Poor correlation between wind and near-bottom current was also noted, which may occur when wind direction or duration is too inconsistent to produce a sustained current direction, or when Ekman transport of bottom waters is directed toward a barrier (shoals or barrier island). This may occur in the study area when northeast, east, or southeast winds tend to move bottom waters shoreward. This shoreward movement is hindered by barrier islands and thus the bottom water will be turned and will flow along the isobaths.

The vertical structure and overall current pattern along the nearshore area of Alabama is considered a two-season event with transitional periods (Kjerfve and Sneed, 1984). Winter, with frequent energetic storms and low freshwater imput, is characterized by a well-mixed water column. The regional winter current pattern is dominated by alongshore currents flowing to the west in response to the strong offshore-directed mean winds (Schroeder and others, 1985) (fig. 6). In spring, increased freshwater runoff, coupled with a reduction in mixing energy as a result of fewer and less intense storms, results in the development of a partially stratified water column. Once initiated, stratification is maintained through the summer by solar heating of the surface water and a further reduction of storm-derived mixing. With the reversal and reduction in strength of the prevailing winds to onshore conditions, the regional circulation can reverse to exhibit

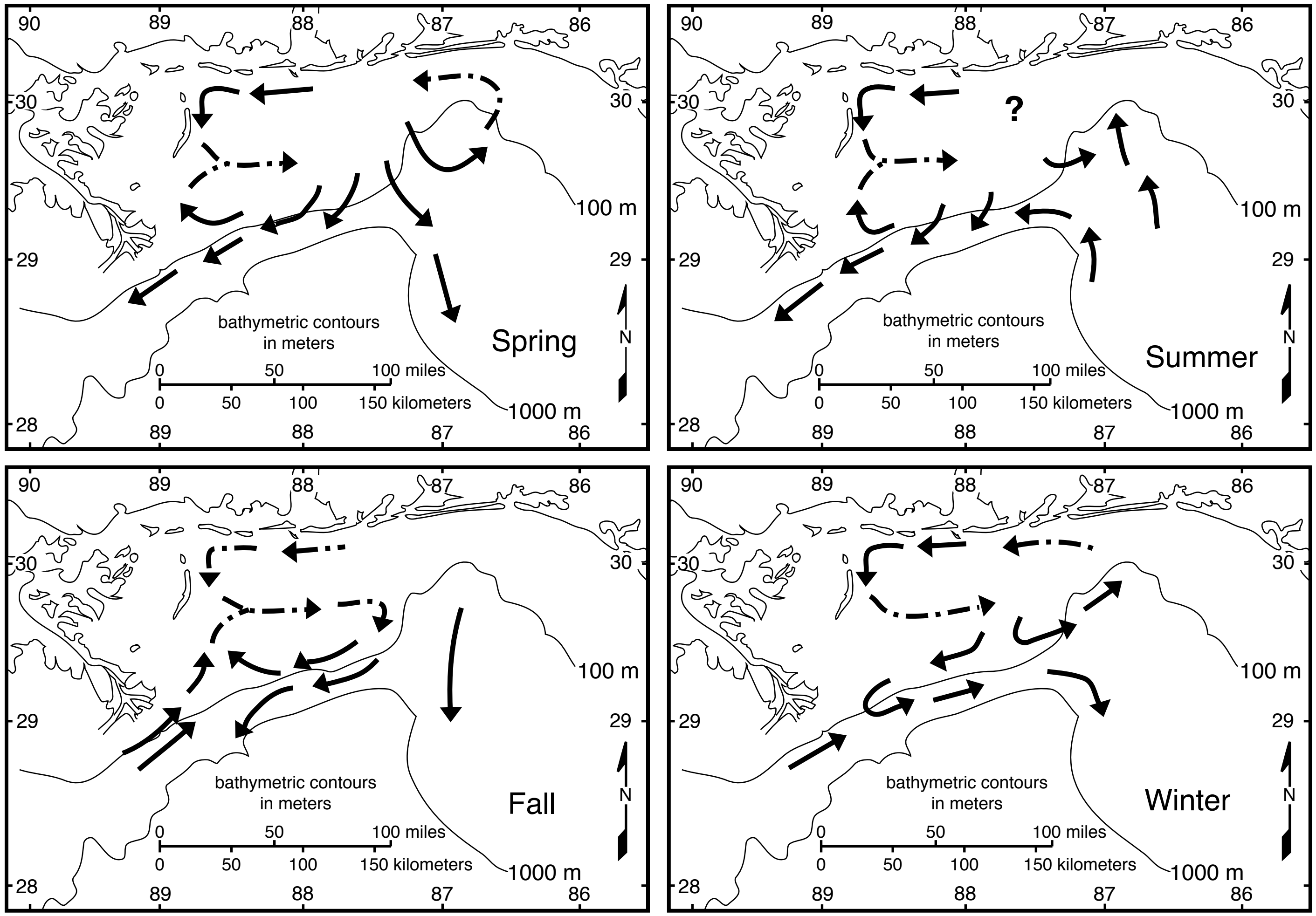


Figure 6.--Circulation patterns on the east Louisiana-Mississippi-Alabama continental shelf (modified from Parker, 1990).

alongshore movement towards the east (Schroeder and others, 1987). Peak current speeds for either flow direction exceed 1 foot per second (fps) (Dinnell, 1988).

Kjerfve and Sneed (1984) further document the seasonal differences in oceanographic conditions in the study area during a one-year investigation (1980-81) offshore of coastal Mississippi and Alabama, based on three 45-day deployment periods at eight current meter stations (surface and bottom) (fig. 7). The mean currents for each of the three current meter deployments, indicated in figure 8 as mean vectors, have different overall current characteristics. During the November 1980 - January 1981 deployment, mean surface flow was towards the west whereas bottom currents flowed north and west away from the barrier islands. During the March-May 1981 deployment, surface currents were largely eastward and bottom currents were to the north at six of the eight stations. During the July-September 1981 deployment, both surface and bottom currents were largely directed towards the west.

Although tidal currents are considered the most energetic currents observed on the shallow shelf, Kjerfve and Sneed (1984) concur that nontidal wind-induced circulation is the principal driving force of low-frequency circulation. In an attempt to generalize predictions of surface and bottom flow directions based on meteorological and current data of Schroeder (1976, 1977), TerEco (1979) constructed probable current regimes on the shallow Mississippi-Alabama shelf during specified sustained wind conditions. The circulation patterns as shown do not take into account open Gulf of Mexico influence, density currents, or storm conditions.

With sustained winds from the west, northwest, north, or northeast, the estimated average near-bottom current speed as measured at Anderson Reef in 20-m water depths is 20 centimeters per second (cm/s) and the maximum sustained hourly speed is 46 cm/s (TerEco, 1979). During northeast winds bottom water tends to move shoreward; however, bottom topography causes this portion of the flow to turn westerly along the shelf.

When winds are sustained from the southeast, south, southwest, or west, the estimated average near-bottom current speed is 26 cm/s and the maximum sustained hourly speed is 60

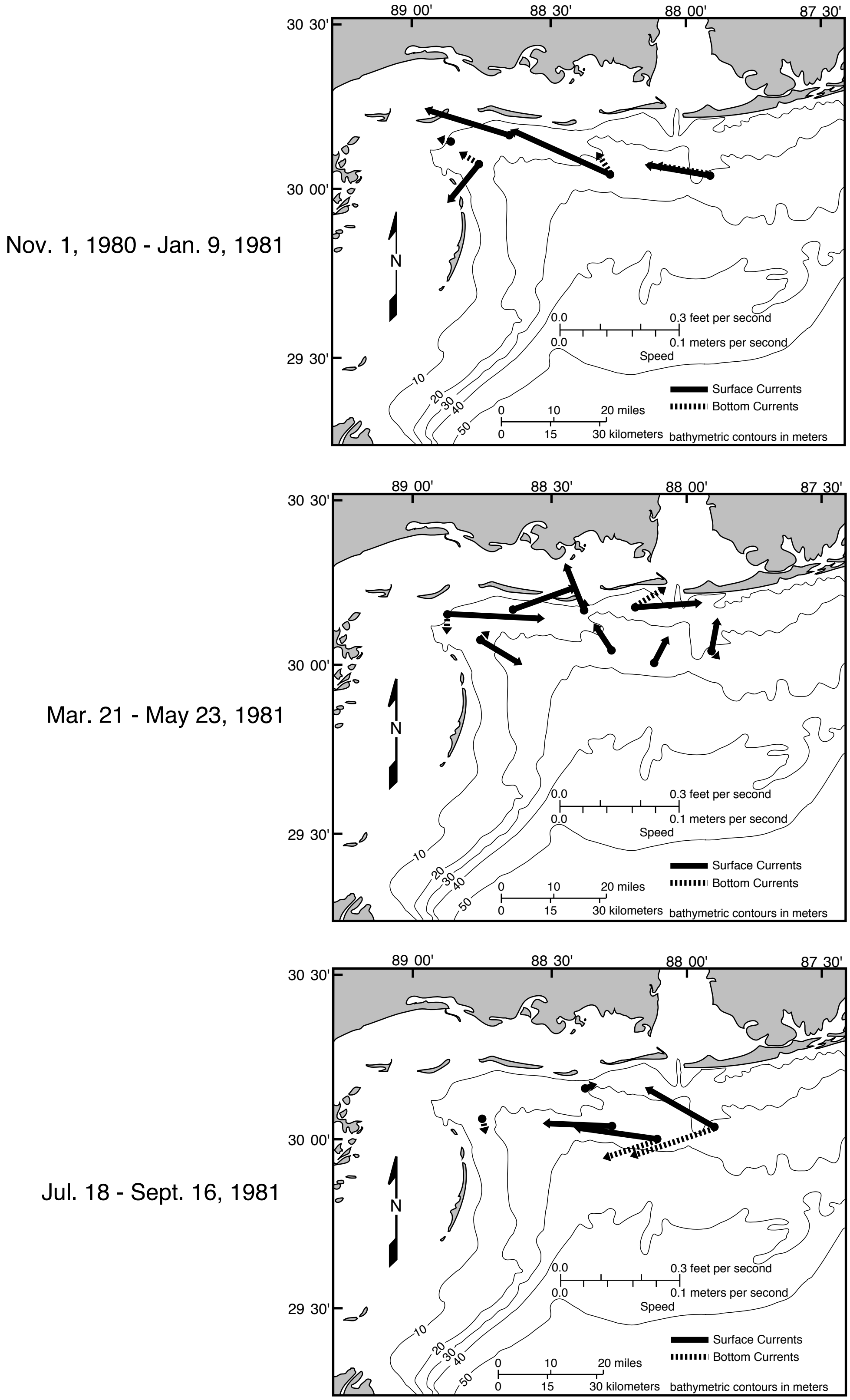


Figure 7.--Mean current velocities on the East Louisiana-Mississippi-Alabama inner continental shelf (modified from Parker, 1990).

cm/s. During periods of sustained southeast winds, bottom water tends to move shoreward; however, bottom topography probably causes that portion of the flow to turn eastward.

Sustained winds from the northeast, east, or southeast yield an estimated average near-bottom current speed of 26 cps and a maximum sustained hourly speed of 60 cps. Under these wind conditions bottom and surface waters may tend to flow shoreward, resulting in an accumulation of water along the coast. The accumulated water will generally inhibit further shoreward movement and may result in bottom transport parallel to shore in the direction of the wind. If winds are sufficiently strong, this accumulated water along the coast may force bottom water away from shore.

SEDIMENT TRANSPORT

Along the seaward sides of Dauphin Island and Morgan Peninsula, longshore currents have the most apparent affect sediment transport (Parker, 1990). Longshore currents typically move east to west at rates of 1.6 to 4.4 f/s and on incoming tides may increase to 4.4 to 8.8 f/s (Foxworth and others, 1962). Sustained northwestern or western winds may cause temporary reversals in the longshore current direction. On the average, 3-day sustained eastward winds are required to reverse the longshore current direction (Abston and others, 1987).

Wind, waves, tides, and currents are the dominant factors controlling water movement within the study area. As a result, these factors are important in sediment transport. In the estuarine systems, tides are the major influence on circulation and sediment transport. Ebb tides disperse tons of fine-grained, suspended sediment through the tidal passes and onto the adjacent shelf. Much of this material is deposited directly southwest of the tidal passes in elongate lenses due to longshore currents. Flood tides, which generally produce weaker currents than ebb tides, inhibit transport of sediment from the estuaries to the shelf. Sustained southerly or southeasterly winds suppress ebb tides while enhancing flood tides, which decreases the transport of suspended sediment load to the shelf. Conversely, northerly winds and high river discharge increase ebb tidal flow and elevate the amount of suspended sediment being transported to the shelf. Within the narrow tidal inlet passes, tidal currents are elevated and fine-grained sediment is winnowed out. As a result, fine- to medium-grained sand occurs in Petit Bois Pass, Main Pass, and Perdido Pass. The amount of bedload coming out of the bays is difficult to quantify; thus, data concerning volume of bedload are not available. Transport of bedload from Mobile Bay is evidenced by a large ebb-tidal delta occurring south of Main Pass.

Tides have little affect on sediment movement on the shelf; however, they may influence sedimentation as they accelerate crossing the shelf (Upshaw and others, 1966). Longshore currents transport sediment along the seaward coasts of the barrier islands. Wave and current activity is primarily responsible for sedimentation on the shelf. Under normal conditions in the study area, waves and currents can move fine- to medium-grained sand in water depths of 20 m; however, little or no net horizontal displacement occurs (Dinnell, 1988). Hurricanes produce waves and currents strong enough to disturb sediment on the outer shelf. Near the shelf edge, sediment is disturbed about once every 5 years (Upshaw and others, 1966).

The amount of sediment entrained in the littoral system along the Mississippi-Alabama barrier islands is not known with confidence. However, Garcia (1977) determined the total net littoral transport at Dauphin Island to be about 196,000 cubic yards (yd^3) per year. This agrees well with the U.S. Army Corps of Engineers (1955) estimate of 200,105 yd^3 per year at Perdido Pass and 212,111 yd^3 per year (U.S. Army Corps of Engineers, 1984) estimate for Petit Bois Island.

DIRECT MEASUREMENT MODELS

Seim and others (1987) collected hourly water level and current data from Mississippi Sound, Mobile Bay, and adjacent Gulf of Mexico for the period April 1980 to October 1981. The current data are summarized in figure 8. In the figure, the arrow length gives the mean surface major axis current amplitude and arrow orientation gives the direction at maximum flood tide. Flood tide surface water in the Gulf of Mexico flows in a generally northern direction at speeds of several

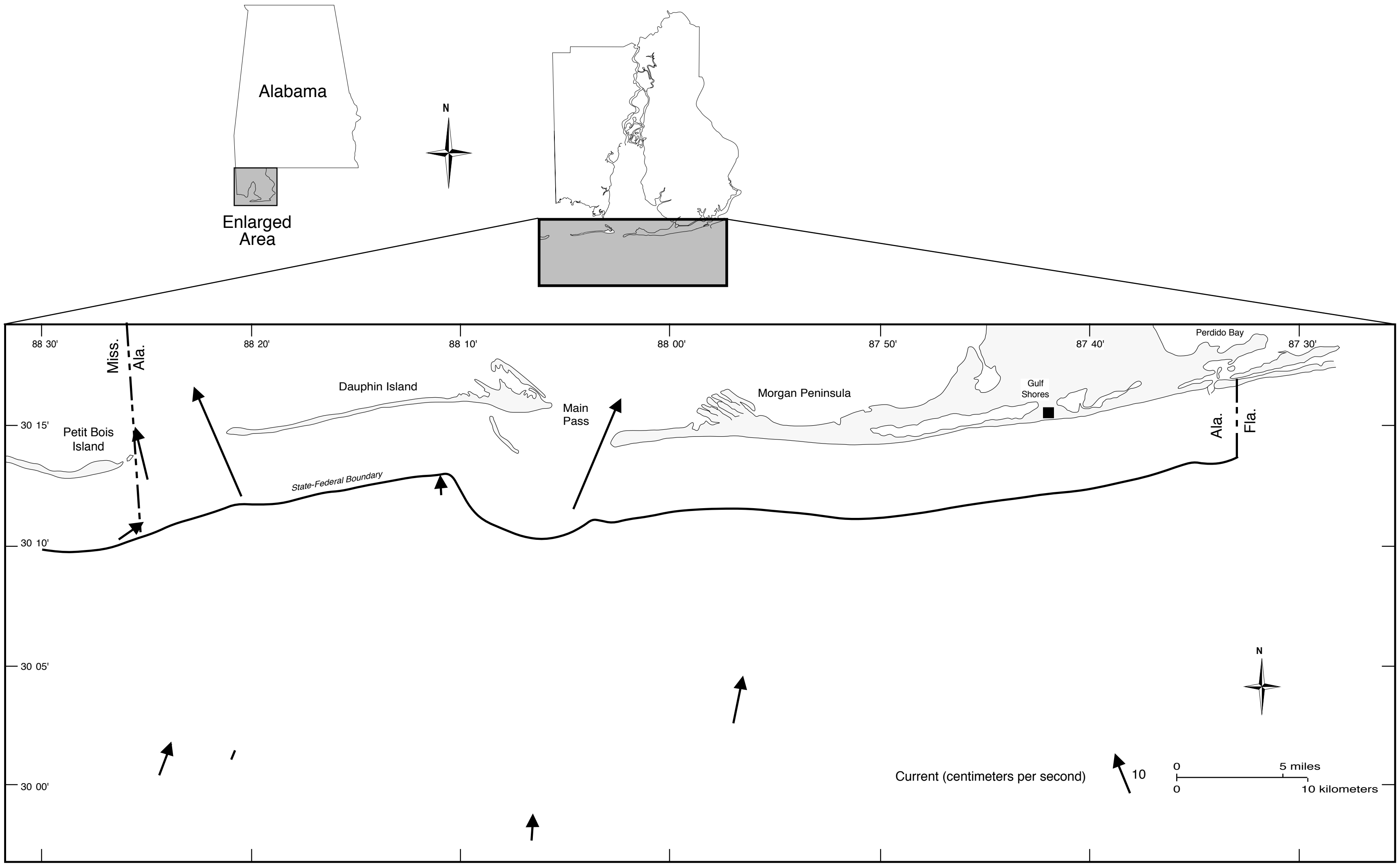


Figure 8.--Index map of the Alabama inner continental shelf showing currents. Arrow length represents surface major current amplitude and orientation gives direction at maximum flood tide (modified from Seim and others, 1987).

centimeters per second, accelerating to reach tens of centimeters per second where water flow is channelized in inlets. Flood tide surface currents in the sand resource site average 8 cm/s to the north-northeast.

The low frequency current variability on the Alabama continental shelf was examined by Chuang and others (1982) using three years (1976, 1978, and 1979) of summer current, sea level, and meteorological records. The current meter mooring was located about 16.1 mi south of the east end of Dauphin Island in about 25 m of water. The latitude-longitude coordinates place the mooring about 12 mi south of the east end of Dauphin Island. The current meter was set at a 1-hour sampling interval and placed 5 m above the sea bottom. Cross-shelf currents (northward) averaged about 2 cm/s for the three-year period with the strongest currents only about 5 cm/s. Alongshore currents (westward) averaged about 5 cm/s for the same time period with the strongest currents about 15 cm/s.

SATELLITE AND AERIAL PHOTOGRAPHY MODELS

Remotely sensed suspended sediment data in coastal regions is a useful tracer for studies of estuarine circulation and estuary-shelf exchange. However, very few of these studies have addressed Alabama inner continental shelf circulation using remote sensing. Satellite imagery has been used to describe estuary-shelf response to cold-air outbreaks (Schroeder and others, 1985) and Mobile Bay discharge sediment plume morphology (Abston and others, 1987; Stumpf and Pennock, 1989; Stumpf and Gelfenbaum, 1990). Regional estuary-shelf exchange is important to an understanding of the general physical circulation and, consequently, transport of suspended sediment (Schroeder and Wiseman, 1986; Wiseman, 1986; Abston and others, 1987; Wiseman and others, 1988).

Abston and others (1987) used Landsat imagery for the years 1973 to 1983 to provide scenes of Mobile Bay sediment plume morphology that can be correlated with coastal processes occurring at the time of the image. Mobile Bay sediment plumes introduce a significant amount of suspended sediment to the inner continental shelf of Alabama and Mississippi. The plumes may extend along the inner continental shelf 22 mi east and west of Main Pass and offshore as far as 30 mi (Abston and others, 1987). Reworking of sediment as a result of normal wave activity is limited to the very nearshore area. Transport of sediment from Mobile Bay onto and across the shelf, under normal conditions, is due primarily to tidal flushing and longshore currents. Wind wave resuspension of both estuarine and shallow shelf sediment occurs during cold-air outbreaks, from November through April (Schroeder and others, 1985). Intensified wave activity associated with hurricanes and tropical storms, is an important factor in the reworking of shelf sediment.

Schroeder and others (1985) defined four morphological types of Mobile Bay sediment plumes. Measurable parameters of plume morphology are area, length, width, and orientation that were correlated with environmental forcing parameters (river discharge, the time elapsed since the last high tide, predicted tidal range, and wind speed and direction). An increase in plume area is generally correlated with higher river discharge. Daily tides initially flush turbid water from Mobile Bay onto the shelf. Although the tidal range, to a large extent, determines the volume of water introduced to the shelf, the plume area determined by imagery appears influenced more by the time since the last high tide. Once the plume is on the shelf, its orientation and dispersal pattern is influenced by surface currents and local wind. Plume orientation seems dependent on alongshore current direction. Deflection of plumes is usually westward, corresponding to the mean westward flow of the inner shelf, but sufficient eastward winds may reverse the inner shelf currents and deflect plumes eastward. Plume size is also affected by an Ekman transport that is related to alongshore wind directions. Water is forced offshore as winds blow to the east; winds to the west force water toward shore. Plumes are dispersed and carried seaward as winds blow to the east and are confined to the inner shelf area as winds blow to the west. Generally, high values of river discharge, tidal range, and time interval since the last high tide, along with winds to the east or southeast, produce the most favorable conditions for the development of large plumes.

Dinnel and others (1990) quantified the relationships between Mobile Bay sediment plume morphology and environmental forcing parameters discussed by Abston and others (1987). Dinnel and others (1990) used correlation and regression analyses to determine statistical relationships between plume morphology and environmental forcing. They found that plume morphology defined by area, length, and width, are primarily related to river discharge with modulating effects due to the tides. Up to a certain level of river discharge, 4,500 cubic meters per second, plume size is directly related to tide phase - the longer the tide has ebbed, the larger the plume. Above this level the river discharge dominates the plume size. Yet, even at times of peak river discharge, the tidal range and phase modifies the plume size.

Local winds, either across or alongshore do not seem to be significantly related to plume size. Yet, the alongshore wind, are well correlated with the orientation of the discharge plume. The direction of the alongshore current is related to the wind direction, so the orientations of the discharge plumes are thought to be a result of advection by the local current - an indirect result of the alongshore winds - as well as a result of direct momentum transfer from the wind.

COMPUTER MODELS

Numerical models for simulation of Mobile Bay system waters have undergone rapid development in the last ten years. Both improved model-formulation techniques and improved digital-computer capabilities have stimulated the increased use of, and confidence in, these models. The first-generation hydrodynamic models (examples include April and Hill, 1974; April and Liu, 1975; April and Ng, 1976a, b) were restricted to a constant spatial step size and fairly simple boundary conditions. For example, finite difference cells were either land or water with no provisions for "drying" or "flooding" of cells during the modeling process. Second-generation hydrodynamic models (examples include April and others, 1975; April and Hu, 1979; Raney and others, 1984) introduced improved boundary conditions for the finite difference cells, including an inundation capability. Sub-grid features also allowed a description of a geometric feature smaller than the selected grid size. For example, a sand bar, smaller than a grid cell, might be represented by a sub-grid barrier restricting flow through one or both faces of the cell. Third-generation hydrodynamic models (examples include Raney, 1984, 1985; Raney and Youngblood, 1987) introduced a variable spatial grid capability allowing a smaller spatial step, where required, for proper resolution of physical detail.

It is important to recognize that numerical modeling of hydrodynamic systems is not an academic exercise with little relationship to the physical world. Any computer model will provide an investigator with an answer to a question. However, the numerical hydrodynamic model, when properly applied and verified, is an extremely powerful predictive tool and a viable, cost effective alternative to physical (scale) modeling or extensive oceanographic data collection.

In order to establish representative monthly salinity and velocity distributions in Mobile Bay, Raney and others (1989a) applied a two-dimensional, depth-averaged finite difference numerical model with average monthly boundary conditions. The numerical model was previously calibrated and verified using surface elevations, velocity, and salinities (Raney and others, 1989a). Average monthly tidal regimes, winds and fresh water inflow were collected from the literature and provided by the U.S. Army Corps of Engineers, Mobile District. These average monthly values allow the establishment of required boundary conditions for the numerical model.

For each month of the year, a set of reasonable initial conditions was established and a 24-hour cycle of tide and river inflow boundary conditions was applied to the numerical model (Raney and others, 1989a). The long-term monthly average wind speed and direction was held constant in both magnitude and direction. The numerical model was run for a total of three cycles (72 hours). The first two cycles were used to establish essentially repetitive conditions in Mobile Bay with results presented for hours 48 through 72 of the numerical simulation. Representative velocity plots are presented at hourly intervals for each month of the year by Raney and others (1989a). The salinity contours are presented in a separate report (Raney and others, 1989b).

The numerical model results appear to be generally consistent with available data (Schroeder, 1976; Bault, 1972) for Mobile Bay. The movement of high salinity water up the main channel is very apparent in the monthly salinity contours. Figure 9 shows the 60 hours (ebb tide) and 72 hours (flood tide) for the months of January and July in the Gulf of Mexico southeast of Main Pass (Raney and others, 1989a).

SURFACE SEDIMENT

GRAIN SIZE

The Mobile-Tensaw River system drains about 34,600 square miles (mi^2) in the states of Alabama, Georgia, and Mississippi (Mettee and others, 1989). These areas include terrains of the Valley and Ridge, Appalachian Plateau, Piedmont, and Coastal Plain physiographic provinces (fig. 10). The entrained sediment of this stream system, therefore, has been derived from sedimentary, igneous, and metamorphic rocks.

The Valley and Ridge and Plateau areas include sequences of Paleozoic clastic sediments, such as sandstone, shale and conglomerate; and carbonate rocks, which are in part chert-bearing. Lithologies of the Piedmont area include granite and granite gneiss, quartzite, schist and other metamorphic lithologies. Coastal plain areas include sediments derived primarily from the Valley and Ridge and igneous and metamorphic areas.

The major lithologic contributions to fluvial deposits, and ultimately to Gulf sediments from the areas described above include gravel, sand, silt and clay-sized quartz, quartzite, and chert. In addition, many accessory minerals such as zircon, rutile, tourmaline, kyanite, ilmenite, monazite, garnet, hornblende, and others, are derived from these areas and ultimately become minor constituents of Gulf sediments. The Coastal Plain area consists of poorly consolidated sedimentary rocks which are derived, in part, from the Valley and Ridge and Piedmont terrains. Erosion of this area contributes sand, clay, gravel, and detrital heavy minerals to the fluvial deposits. Mobile Bay and eastern Mississippi Sound are filled with sediments consisting of fluvial, marine, estuarine, and deltaic clay, silt, sand, and gravel.

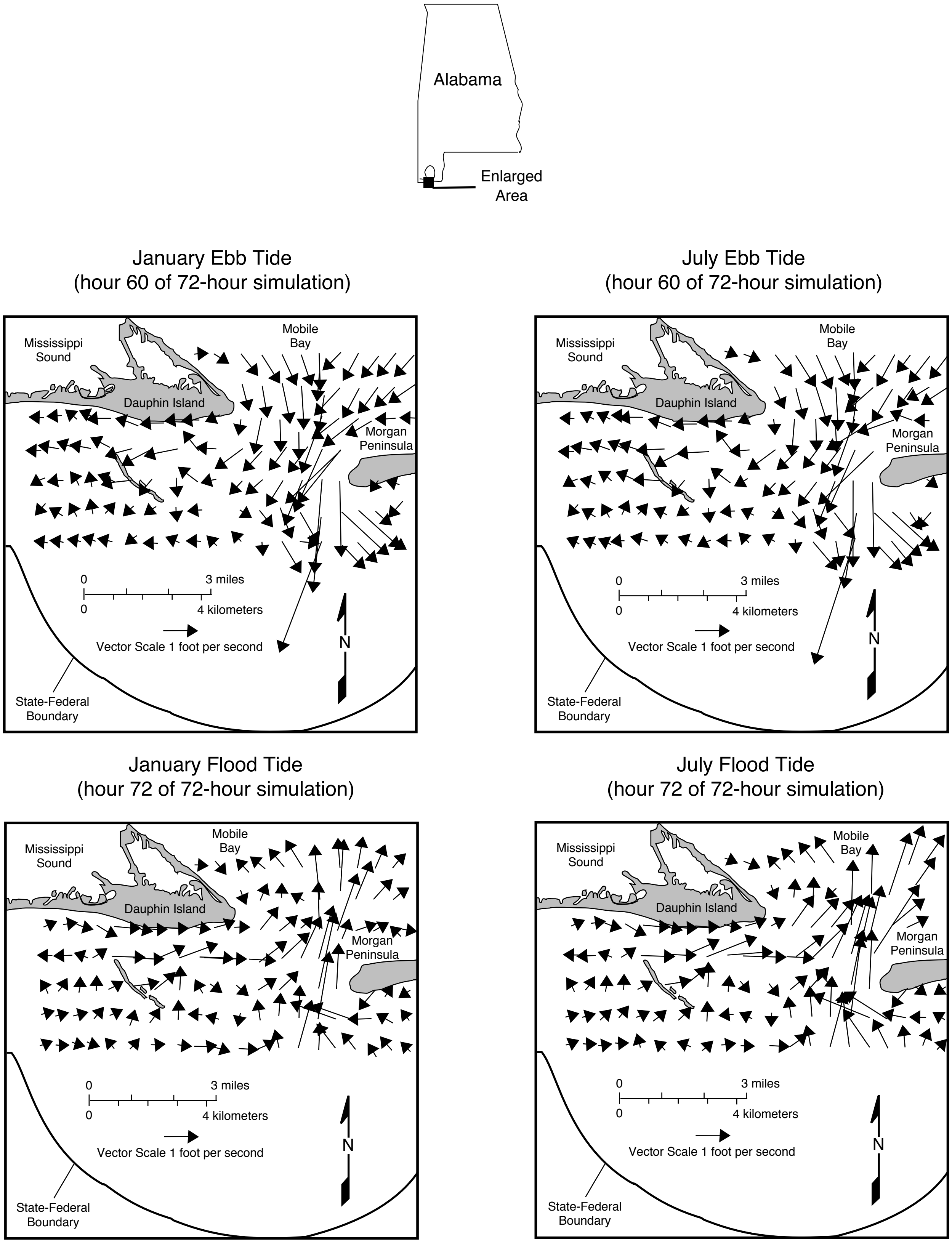


Figure 9.--Maps showing surface water velocity vectors generated by a two-dimensional, depth-averaged finite difference numerical model of average monthly conditions for January and July (modified from Raney and others, 1989).

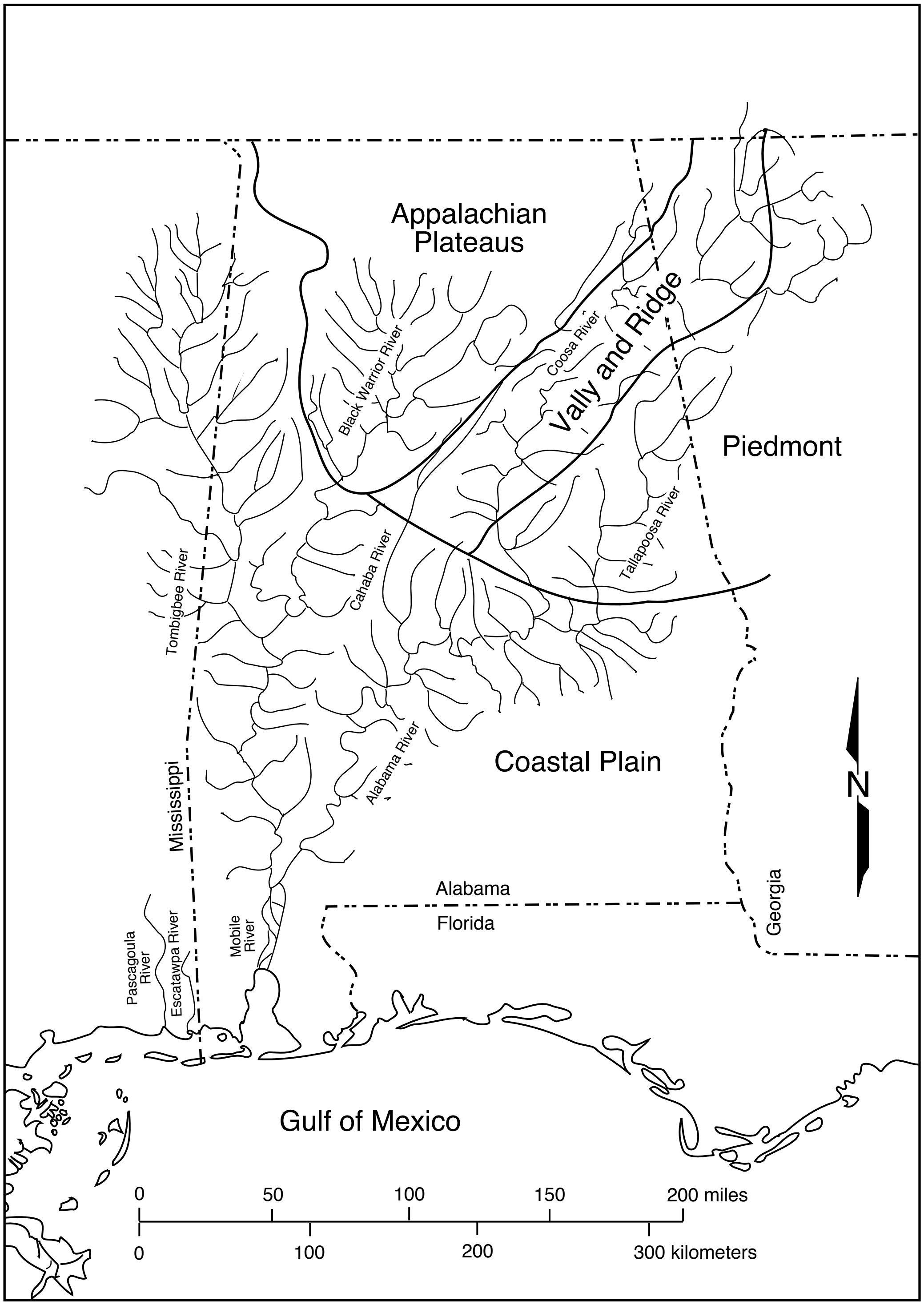


Figure 10.--Mobile River drainage basin (modified from Hardin and others, 1976).

The Louisiana-Mississippi-Alabama shelf is part of a triangular region that includes parts of offshore Louisiana, Mississippi, Alabama, and westernmost Florida (fig. 4). Ludwick (1964) divided the shelf into six facies (fig. 4). The study area lies in the nearshore fine-grained facies which is comprised of sand, muddy sand, sandy mud, and mud (fig. 4). These sediments are deposited at water depths generally less than 60 ft and in a zone about 7 mi wide.

The most recent surface sediment texture map that includes the study area is from 1984 (U.S. Army Corps of Engineers, 1984). Parker and others (1997) constructed a surface sediment texture map for the Alabama EEZ utilizing the U.S. Army Corps of Engineers (1984) map and data from several sources (fig. 11). Granulometric analysis of bottom samples collected from the present study was used to update the surface sediment texture map of Parker and others (1997). Sediment types were classified according to the ternary diagram on the explanation of symbols and patterns page in appendix B. The seafloor of the study area consists of sand with patches of muddier sediment scattered throughout the western third of the study area (fig. 12).

Geographic variation in sea bottom sediment type is subject to prevailing hydrologic and oceanographic conditions (many of which show distinct seasonal variation), which on the Alabama inner continental shelf constantly rework and redistribute surficial sediments. Heterogeneity of nearshore sediment is attributed to Holocene transgression, variation in local bathymetry, changes in sediment transport pathways, reworking by wave activity, and sedimentation associated with sediment plumes emanating from Mobile Bay (Swift and others, 1971; Pyle and others, 1975; Abston and others, 1987; Wiseman and others, 1988; Chuang and others, 1982). Tidal inflow and outflow through Main Pass redistributes estuarine sediment in the southern half of Mobile Bay and transports clays and silts out of Mobile Bay. Most of the sediment exiting Mobile Bay is deposited south to west of the Main Pass in response to the predominant westward directed littoral drift, forming an ebb-tidal delta (U.S. Army Corps of Engineers, 1979). During summer months, some of the sediment fines move eastward in response to an eastward component of the longshore drift (U.S. Army Corps of Engineers, 1979). Deposition of sand from ebb-tidal sediment plumes occurs seaward of Main Pass on the ebb ramp, with clay and silt being

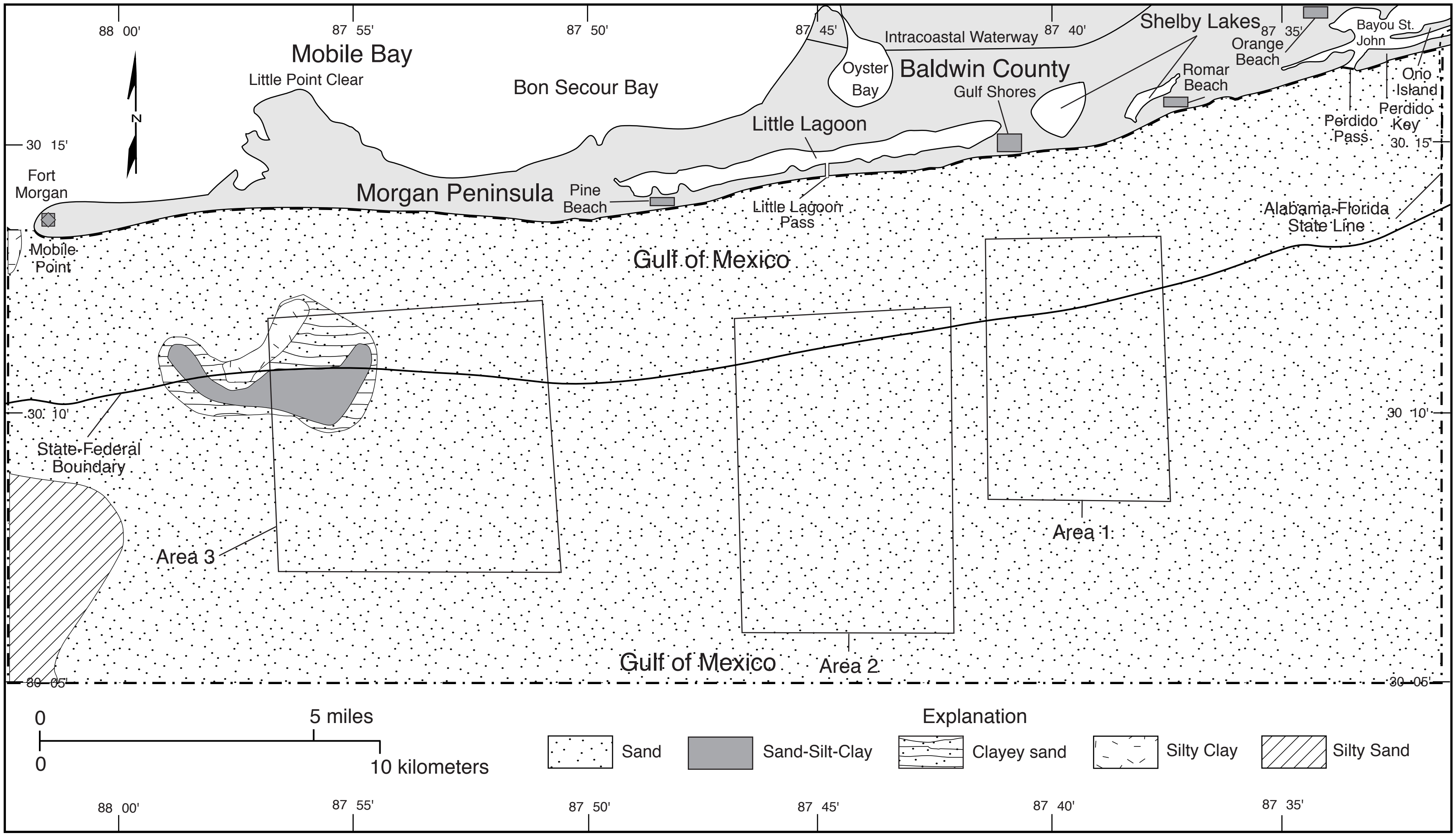


Figure 11.--Surface sediment texture map compiled from pre-existing sediment texture data in the east Alabama inner continental shelf study area (modified from Parker and others, 1997).

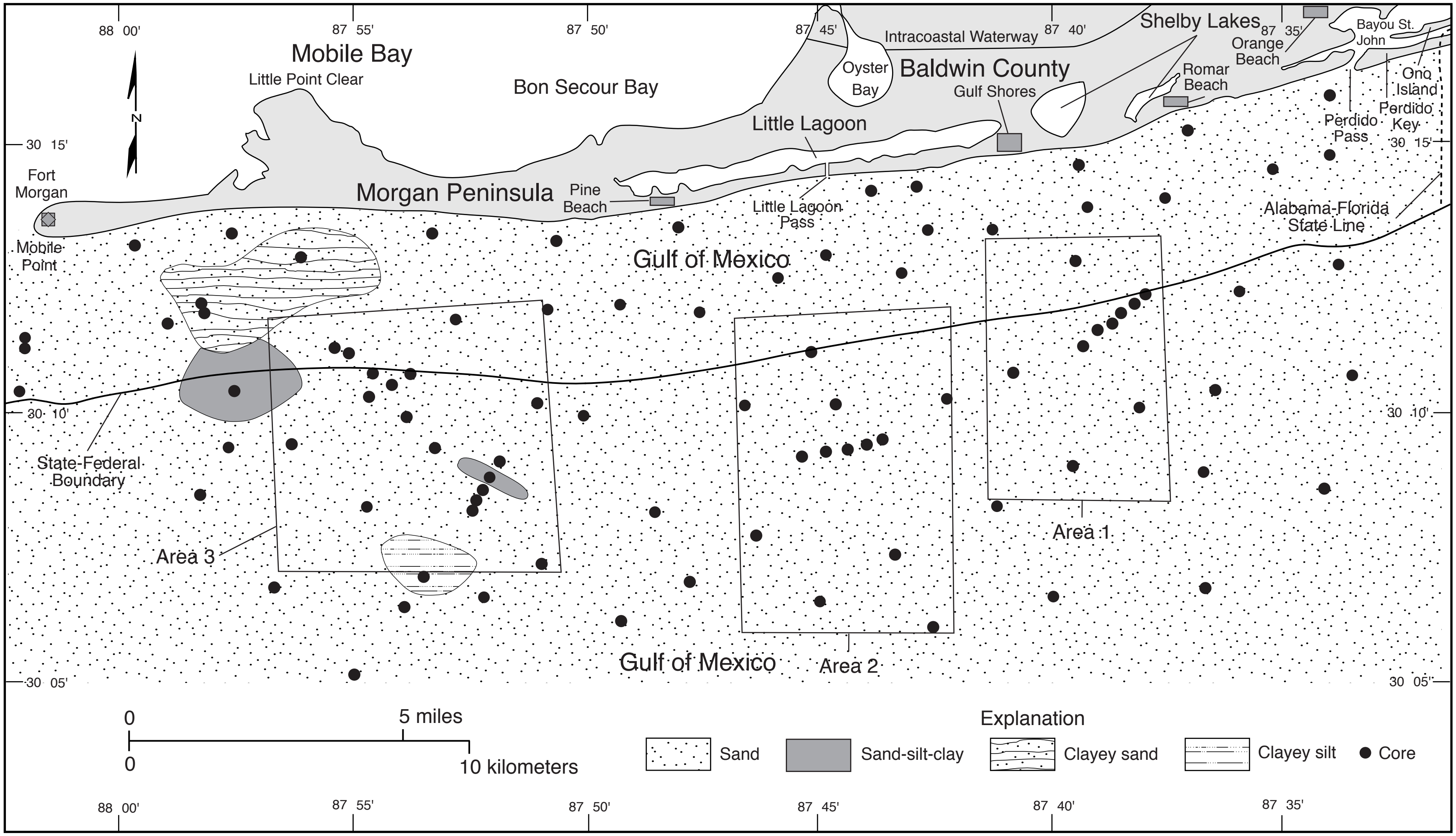


Figure 12.--Surface sediment texture distribution in the east Alabama inner continental shelf study area.

deposited on the shelf seaward of the ebb shield, which includes the western third of the study area (figs. 3, 12).

Despite the homogeneity of lithofacies and sediment texture at the sea bottom, the small-scale distribution of the lithofacies is very patchy (Parker and others, 1997). It is expected that in the study area, utilizing a sampling net finer than that used in the present study, lithofacies distribution will be variable. This patchiness may be the result of the interplay between relict sediment distribution, present topography and hydrodynamics, and local differences in shell content. Present knowledge of topography and circulation is not sufficiently advanced to predict lithofacies patterns on a small scale.

HEAVY MINERALS

Foxworth and others (1962) studied the heavy mineral assemblage of the Mississippi-Alabama barrier islands and found a tourmaline-kyanite suite of heavy minerals. This suite falls in the eastern Gulf of Mexico heavy mineral province, which is characterized by a relatively high content of ilmenite, staurolite, kyanite, zircon, tourmaline, and stillimanite, and by low percentages of magnetite, amphibole, and pyroxene (Hsu, 1960; Van Andel and Poole, 1960; Doyle and Sparks, 1980). Barrier island sand is thought to have been derived from erosion of pre-Holocene coastal plain sediment and reworking of Pleistocene inner continental shelf alluvial deposits (Rucker and Snowden, 1989). Concentrations of heavy minerals occur as thin laminae to medium beds in back-barrier beaches and coastal eolian dunes. Foxworth and others (1962) proposed that longshore currents, waves, and tides move heavy minerals onshore, while storm waves, winds, and rain runoff concentrate these minerals into layers.

Upshaw and others (1966) found concentrations of heavy minerals greater than 4 percent in Petit Bois Pass surficial sediment. Studies by Stow and others (1975), Drummond and Stow (1979), and Woolsey (1984) found heavy mineral concentrations of up to 2.4 percent in surficial shoreface sediment off the west end of Dauphin Island and in Pelican Bay. Stow and others

(1975) suggested that these shore-parallel elongated heavy mineral concentrations are a result of a combination of longshore transport and wave action. The ultimate source of heavy minerals for nearshore Alabama inner continental shelf sediments is the igneous-metamorphic complex of the southern Appalachian Mountains.

Quantitative study of heavy minerals was not part of the present study. However, microscopic examination of seafloor sediment samples and subsamples collected from vibracores and borings to describe sediment texture indicates that heavy minerals are present in amounts ranging from trace to about one percent. In addition, no concentrations of heavy minerals, such as laminae or beds, were observed within the vibracores or borings.

CLAY MINERALS AND CARBONATES

On the shelf, smectite and kaolinite are the predominant clay minerals, with illite present in smaller quantities (Doyle and Sparks, 1980). Smectite, which is characteristic of the Mississippi River and Mobile-Tensaw River systems, is predominant on the continental shelf. Smectite increases while kaolinite decreases offshore over most of the continental shelf south of the study area (Doyle and Sparks, 1980).

Ryan and Goodell (1972) found that carbonates were derived from the presence of whole and disarticulated bivalve shells and that most of the gravel-sized clasts were composed of shell debris. Carbonate content increases southwest of Main Pass (Ryan and Goodell, 1972).

PREVIOUS INVESTIGATIONS

Seafloor sediment texture and mineralogy in the study area have been mapped by Foxworth and others (1962), Ryan (1969), Ryan and Goodell (1972), and Parker (1990).

The Quaternary stratigraphy of portions of the study area has been investigated by several researchers that include Kindinger and others (1994), McBride and Byrnes (1995), McBride and others (1996), McBride (1997), and Parker and others (1997).

DATABASE

The database for this study constitutes lithologic descriptions of 44 vibracores listed by Parker and others (1997) (table 1). Vibracore SR-13 was omitted as it lay outside the study area.

Seven foundation borings (originally obtained from Exxon Company, U.S.A.) were available for use in the study (table 2). Three of the borings are from Hummell (1996). Lithologic descriptions and columnar sections of four borings were generated solely for this study. In addition, unpublished lithologic descriptions and columnar sections of ten vibracores collected by the GSA and U.S. Geological Survey in 1992 were used in the present study (table 2).

The available data were used to guide the collection of 30 vibracores and matching seafloor grab samples from the study area (table 3, SR-90-119). Vibracores SR-85-89 were collected to check the status of a mud layer deposited in sand resource area 4 by Hurricane Danny in 1997 (fig. 13, table 3). The layer covered portions of a sand deposit that was mapped by the GSA and MMS as a potential source of Dauphin Island beach nourishment sand. The 35 new vibracores totaled 469 ft of core and were collected August 28-31, 1998. The locations of the 91 vibracores and borings used in this study are shown as figure 14. A columnar section illustration for each boring and vibracore appears in appendix A (figs. A-1 to A-96).

Shallow seismic records were collected and/or analyzed by various researchers for portions of the study area. The unavailability and shortcomings of data by Brande (1983), Raymond and others (1993), and Dr. Louis Bartek, University of Alabama at Tuscaloosa, have been discussed by Hummell (1996). Many of these data were superseded by shallow seismic records collected and analyzed by the GSA and U.S. Geological Survey in 1990-93, the results of which were

Table 1.--Summary of information pertaining to vibracores used in study (modified from Parker and others, 1997)*

Core Number	Core length (feet)	Elevation above sea level (feet)	Loran-W	Loran-Y	Latitude	Longitude
SR-1	10.07	-49.1	12834.3	47073.6	30 11' 08"	87 55' 05"
SR-2	6.09	-35.1	12839.3	47071.8	30 10' 43"	87 54' 34"
SR-3	8.16	-37.1	12837.8	47070	30 10' 19"	87 54' 41"
SR-4	9.43	-40	12842.9	47071	30 10' 31"	87 54' 13"
SR-5	16.48	-30.9	12847.3	47071.8	30 10' 41"	87 53' 47"
SR-6	14.98	-28.9	12846.4	47068.3	30 09' 55"	87 53' 50"
SR-7	8.13	-34.1	12851.5	47065.6	30 09' 18"	87 53' 17"
SR-8	17.97	-37.1	12865.3	47064.7	30 09' 05"	87 51' 55"
SR-9	3.64	-47.1	12800	47061.4	30 08' 27"	87 58' 16"
SR-10	18.95	-50.1	12820	47065.9	30 09' 25"	87 56' 22"
SR-11	12.29	-50.1	12814.6	47053.6	30 06' 41"	87 56' 43"
SR-12	17.68	-51	12831.2	47046	30 05' 01"	87 54' 59"
SR-14	8.35	-50.1	12843	47052	30 06' 19"	87 53' 55"
SR-15	9.39	-62.1	12848	47054.7	30 06' 54"	87 53' 28"
SR-16	8.16	-51	12857.6	47060.1	30 08' 05"	87 52' 25"
SR-17	8.45	-47.1	12859.8	47061.1	30 08' 18"	87 52' 25"
SR-18	14.37	-40	12862	47062.1	30 08' 31"	87 52' 13"
SR-19	9.85	-41.9	12863.7	47063.2	30 08' 45"	87 52' 04"
SR-20	16.93	-37.1	12875	47069.7	30 10' 04"	87 51' 10"
SR-21	5.46	-54	12874.1	47055.8	30 07' 07"	87 50' 55"
SR-22	6.14	-51	12890.4	47050.8	30 06' 03"	87 49' 14"
SR-23	9.13	-48.1	12905.7	47050	30 06' 43"	87 47' 47"
SR-24	7.54	-48.1	12921.3	47058.6	30 07' 41"	87 46' 20"
SR-25	17.84	-56.9	12958.3	47050.2	30 05' 54"	87 42' 32"
SR-26	10.08	-51	12951.3	47056.6	30 07' 15"	87 43' 21"
SR-27	3.93	-43.9	12950.6	47066.9	30 09' 26"	87 43' 37"
SR-28	8.09	-38	12947	47066.6	30 09' 23"	87 43' 58"
SR-29	7.77	-42.9	12942.5	47066	30 09' 16"	87 44' 23"
SR-30	2.89	-46.2	12938	47065.7	30 09' 12"	87 44' 49"
SR-31	3.93	-44.9	12933	47065.2	30 09' 06"	87 45' 19"
SR-32	17.75	-39	12941	47070.1	30 10' 08"	87 44' 37"
SR-33	2.21	-41.9	12936.7	47074.4	30 11' 05"	87 45' 07"
SR-34	12.06	-38	12984	47073.3	30 10' 46"	87 40' 47"
SR-35	12.38	-44.9	13018.5	47053.7	30 06' 38"	87 36' 41"
SR-36	5.92	-75.1	13018.8	47053.8	30 06' 39"	87 36' 39"
SR-37	11.25	-60.1	13045.9	47062.8	30 08' 30"	87 34' 11"
SR-38	16.45	-51	13025.1	47071.7	30 10' 22"	87 36' 25"
SR-39	13.39	-41	13011	47080.2	30 12' 11"	87 37' 58"
SR-40	17.29	-40	13008.5	47079.2	30 11' 59"	87 38' 11"
SR-41	8.45	-34.1	13005.8	47078.4	30 11' 49"	87 38' 26"
SR-42	4.16	-44.9	13002.9	47077.5	30 11' 38"	87 38' 42"
SR-43	9.26	-38	13000.1	47076.8	30 11' 29"	87 38' 58"
SR-44	5.95	-38	12996.6	47076	30 11' 19"	87 39' 17"
SR-45	17.75	-30.9	12996.6	47082.9	30 12' 48"	87 39' 25"

* SR-13 and SR-46 thru 59 are located outside of study area and were not used.

Table 2.--Summary of information pertaining to vibracores and foundation borings used in study

Source*	Vibracore or Foundation Boring Number	Elevation above sea level (feet)	Core Length (feet)	Latitude	Longitude
GSA	G-6	-10	2.03	30 13' 10"	87 59' 43"
GSA	G-7	-7.5	3.28	30 13' 22"	87 57' 36"
GSA	G-8	-13.1	4.13	30 13' 22"	87 53' 20"
GSA	G-9	-13	5.84	30 13' 11"	87 50' 35"
GSA	G-10	-12.9	5.25	30 13' 27"	87 48' 00"
GSA	G-11	-7.4	3.15	30 14' 05"	87 43' 52"
GSA	G-12	-10.3	2.66	30 14' 11"	87 42' 55"
GSA	G-13	-11.7	3.3	30 14' 37"	87 39' 25"
GSA	G-14	-9.8	3.01	30 15' 14"	87 37' 01"
GSA	G-15	-11.4	3.18	30 15' 53"	87 34' 08"
Exxon**	84-1115, B-1	-20.5	327	30 11' 38"	88 02' 09"
Exxon	85-1071, B-1	-37	240	30 12.9'	87 56.1'
Exxon	85-1072, B-1	-30	352	30 11.2'	87 55.4'
Exxon	0183-3144, B-1	-47	314	30 11.9'	87 58.2'
Exxon**	0201-1071-1, B-1	-21	250	30 11' 10"	88 02' 07"
Exxon**	1188-1314, B-III-7	-26	32	30 10' 22"	88 02' 16"
Exxon	1188-1314, B-D-2 & 2A	-45	248.5	30 12.1'	87 58.3'

* Geological Survey of Alabama unpublished vibracore; Exxon Company, U.S.A. unpublished foundation boring.

** Modified from Hummell (1996)

Table 3.--Summary of information pertaining to vibracores collected for this study

Core Number	Core length (feet)	Elevation above sea level (feet)	Loran-W	Loran-Y	Latitude	Longitude
SR-85	6.6	-40.4	12719.3	47063.8	30 09.2947'	88 06.2044'
SR-86	9.4	-38.7	12727	47062.5	30 09.0049'	88 05.3719'
SR-87	10.9	-45.7	12719.7	47060.7	30 08.1863'	88 06.3853'
SR-88	17.3	-54.6	12717	47057.5	30 07.7801'	88 06.4098'
SR-89	14.9	-51.6	12722	47057.3	30 07.7078'	88 05.8635'
SR-90	9.5	-44.7	12786	47064	30 09.3426'	87 57.7090'
SR-91	18	-37.7	12795	47075	30 11.7199'	87 59.0351'
SR-92	15.1	-52.8	12808	47069	30 10.3729'	87 57.5736'
SR-93	15.1	-50.9	12835	47060	30 08.2129'	87 54.7685'
SR-94	15.3	-59.9	12860	47052.5	30 06.5133'	87 52.2305'
SR-95	10.8	-39	12885	47068	30 09.9367'	87 50.0617'
SR-96	5.6	-48.7	12900	47060	30 08.0882'	87 48.5306'
SR-97	15.6	-48.8	12920	47069	30 10.1272'	87 46.5963'
SR-98	14.7	-54.7	12934	47052	30 06.3922'	87 44.9794'
SR-99	10.4	-54	12985	47052.5	30 06.5240'	87 39.9661'
SR-100	13.6	-50.1	12974	47062	30 08.1792'	87 41.1886'
SR-101	17.5	-41.1	12965	47070	30 10.2129'	87 42.2718'
SR-102	15.8	-48	13008	47070	30 10.0782'	87 38.0657'
SR-103	13.8	-55.9	13020	47064	30 08.8589'	87 36.7074'
SR-104	13.8	-52.8	13055	47073	30 10.7101'	87 33.4963'
SR-105	15.7	-45.8	13032	47080	30 12.1914'	87 35.9207'
SR-106	12.9	-46.7	13055	47082.5	30 12.7584'	87 33.7903'
SR-107	14.2	-26.7	13055	47092.5	30 14.7777'	87 33.9921'
SR-108	14.4	-38.2	13042	47091	30 14.5115'	87 35.2122'
SR-109	14.1	-34.1	13017	47088	30 14.0175'	87 37.5029'
SR-110	11.9	-35	13000	47087	30 13.8123'	87 39.1861'
SR-111	11.2	-35	12980	47085	30 13.4166'	87 41.2424'
SR-112	17.9	-29.9	12965	47084	30 13.3429'	87 42.6379'
SR-113	9.2	-32.9	12958	47081	30 12.5799'	87 43.1843'
SR-114	15.3	-37.8	12942	47082	30 12.9087'	87 44.8040'
SR-115	14.9	-38.9	12930	47080	30 12.5097'	87 45.8592'
SR-116	11.2	-39.9	12912	47078	30 11.8619'	87 47.5748'
SR-117	10.3	-33	12895	47077	30 12.0220'	87 49.2620'
SR-118	17.8	-34	12878	47077	30 11.8999'	87 50.8130'
SR-119	14.1	-26.1	12858	47075.5	30 11.7324	87 52.7987'

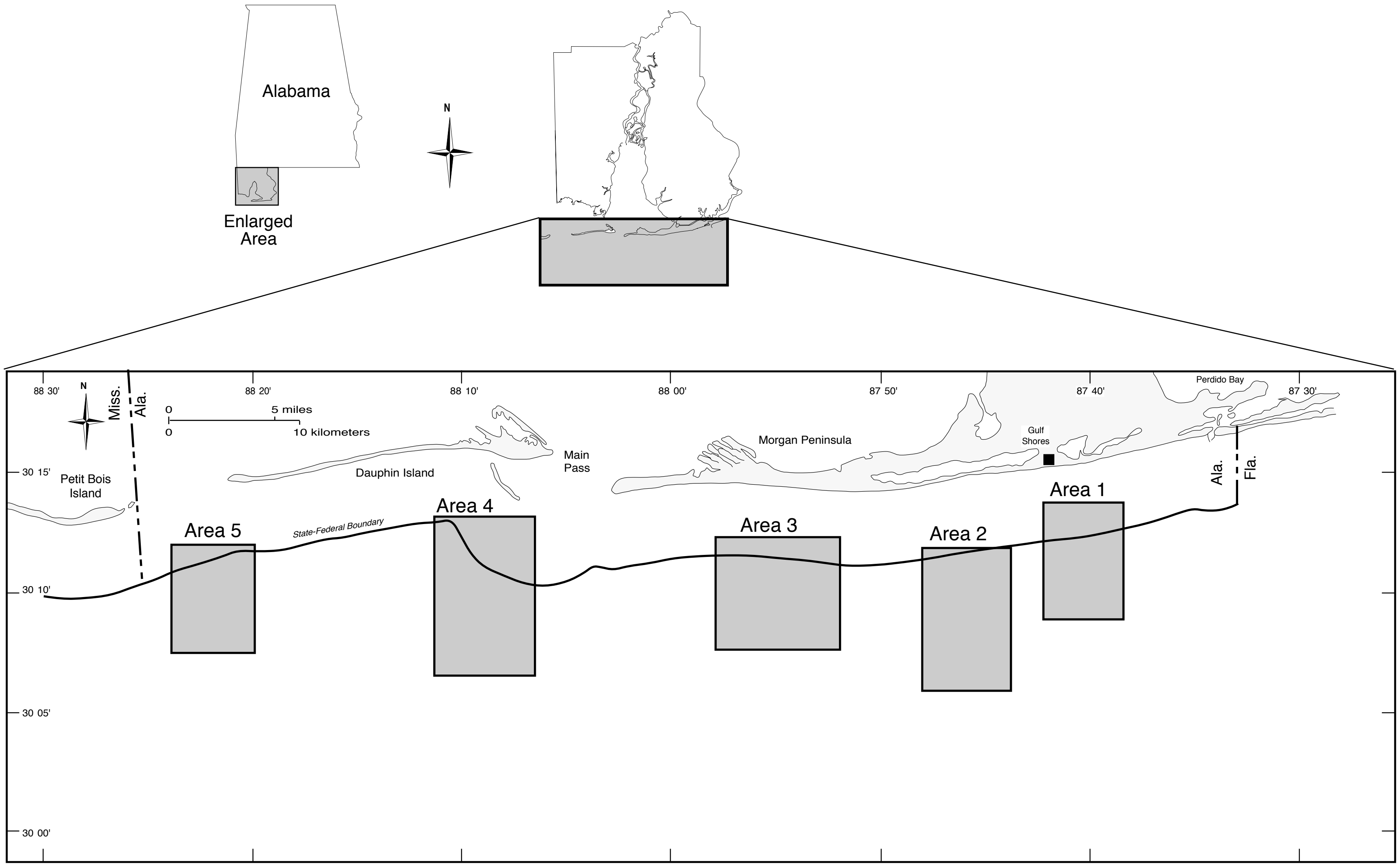


Figure 13.--Index map of EEZ sand resource target areas (modified from Parker and others, 1997).

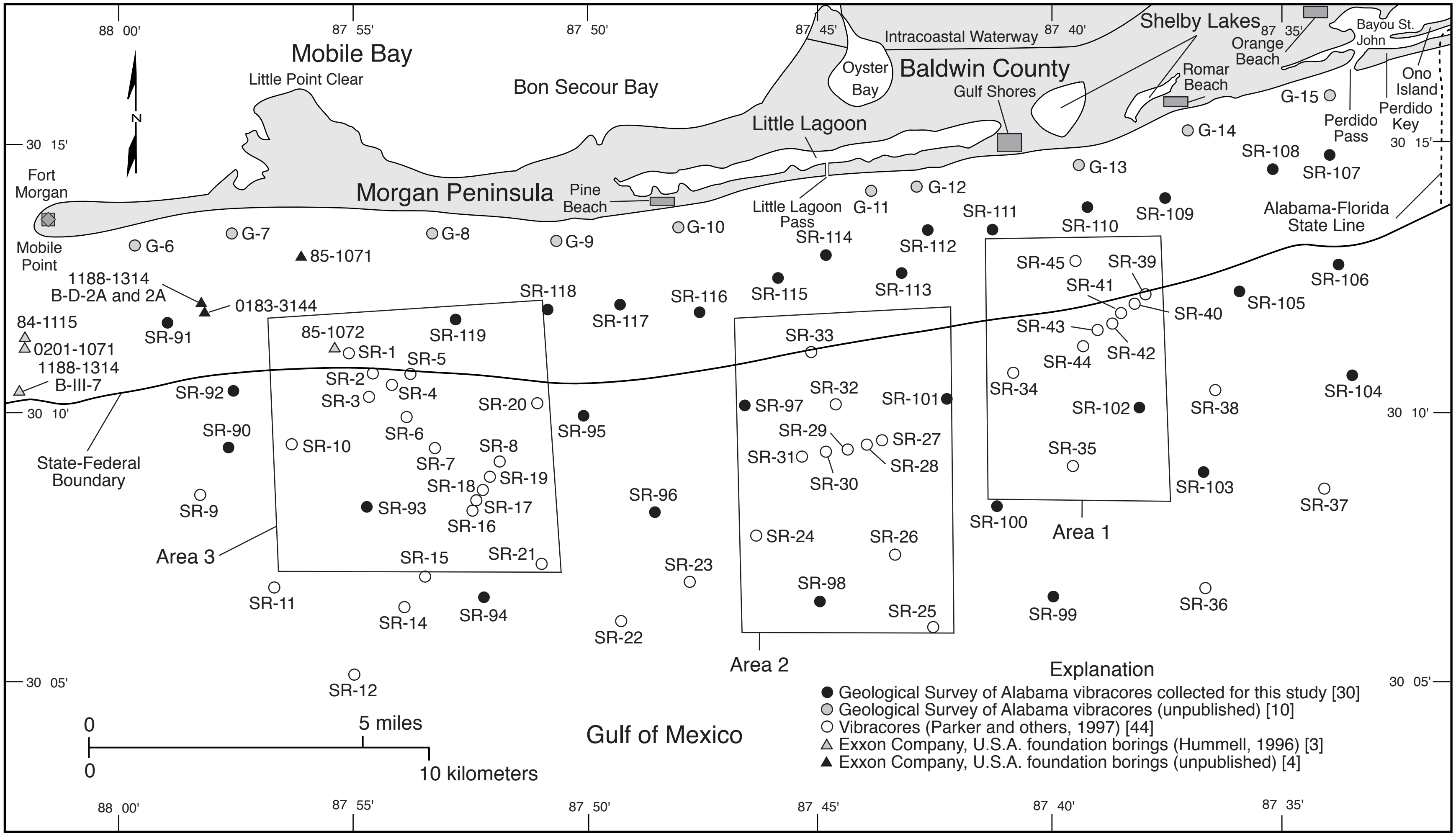


Figure 14.--Map showing locations of vibracores and foundation borings pertinent to the east Alabama inner continental shelf study area.

published by Kindinger and others (1991, 1994). The results of Kindinger and others (1994) were utilized in the present study.

BATHYMETRY

Study area bathymetry was described by Parker and others (1997) (fig. 5). The data used to prepare the bathymetric map were derived from NOAA nautical charts Nos. 11373, 11376, and 11382 (NOAA, 1991a, 1991b, 1991c). Soundings from each of these charts were plotted on a single base map and contoured at 2-ft intervals. A review of historic nautical charts of the study area indicates that bathymetry data on these maps are a collection of many years of data with only certain areas having been recently updated. Bathymetric readings taken at vibracore sites were recorded and compared with the bathymetric map of Parker and others (1997). The comparison showed that the seafloor bathymetry had changed in some areas, but the bathymetric map by Parker and others (1997) remains adequate for describing the general seafloor bathymetry of the study area.

METHODOLOGY

Vibracoring is a technique used to collect relatively undisturbed cores in unconsolidated sediment. The technique has been discussed by Hummell and Parker (1995a, b) and Hummell (1996). The vibracores for this project were collected by GSA personnel aboard the R/V *Kit Jones* owned by the Marine Minerals Technology Center in Biloxi, Mississippi. The vibracoring system employed in this study consisted of a 25-ft tower that served as a guide for a pneumatic vibrator that drove the core tube into the seafloor. A 20-ft long, 3-inch (in) diameter aluminum core tube was used which yielded a maximum core length of about 19 ft. Prior to submerging the coring apparatus, the core tube was filled with air which allowed for better penetration. The core was driven into the sediment to the maximum core length or until refusal. After coring ceased, pressure was released and the core tube was allowed to fill with water to provide a suction and prevent loss of the core during extraction. The cores were extracted using a hydraulic winch and the "A-frame" rigging at the stern of the boat. On deck, the cores were cut into 5-ft sections, capped, and stored on board until the vessel came ashore. The core sections were then transported to GSA for storage, splitting, and analysis. Navigation aboard the vessel was by Geographic Positioning System.

The major steps involved in the laboratory analysis of the vibracores are presented in figure 15. Vibracores were opened for study using a hand-held router. A table mounted device was used for holding each vibracore section during cutting. This holding device was modified from the one described by Meisburger and others (1980). After making two length-parallel cuts (180 degrees apart) through the wall of the core barrel, a knife was passed between the two router cuts to separate the vibracore section into halves.

Once all sections to a vibracore were cut open, the vibracore was reassembled on a platform modified from Hoyt and Demarest (1981) equipped with back drop, foot and meter scales, color and gray scales, and text labels so that the entire vibracore (both halves) could be photographed. Vibracores were photographed indoors with a 35-millimeter camera with a built-in flash and three freestanding flood lights.

The most intact half of each vibracore section was usually chosen as the half to be archived. Both halves of all vibracore sections were used in the lithologic description process but the archive section remained undisturbed. The archive half was placed in permanent storage at GSA.

After photography, the vibracore was described using standard sedimentological techniques. Colors were described by using a Munsell soil color chart. Organic material, when present, was identified and its abundance visually estimated. The extent of bioturbation was described using the bioturbation index of Droser and Bottjer (1986).

After the vibracore was described, samples for textural analysis were taken from the nonarchived half of the vibracore at intervals of 1 foot or less as needed to characterize lithologic units. After the sampling process the sampled vibracore half was placed in archive storage.

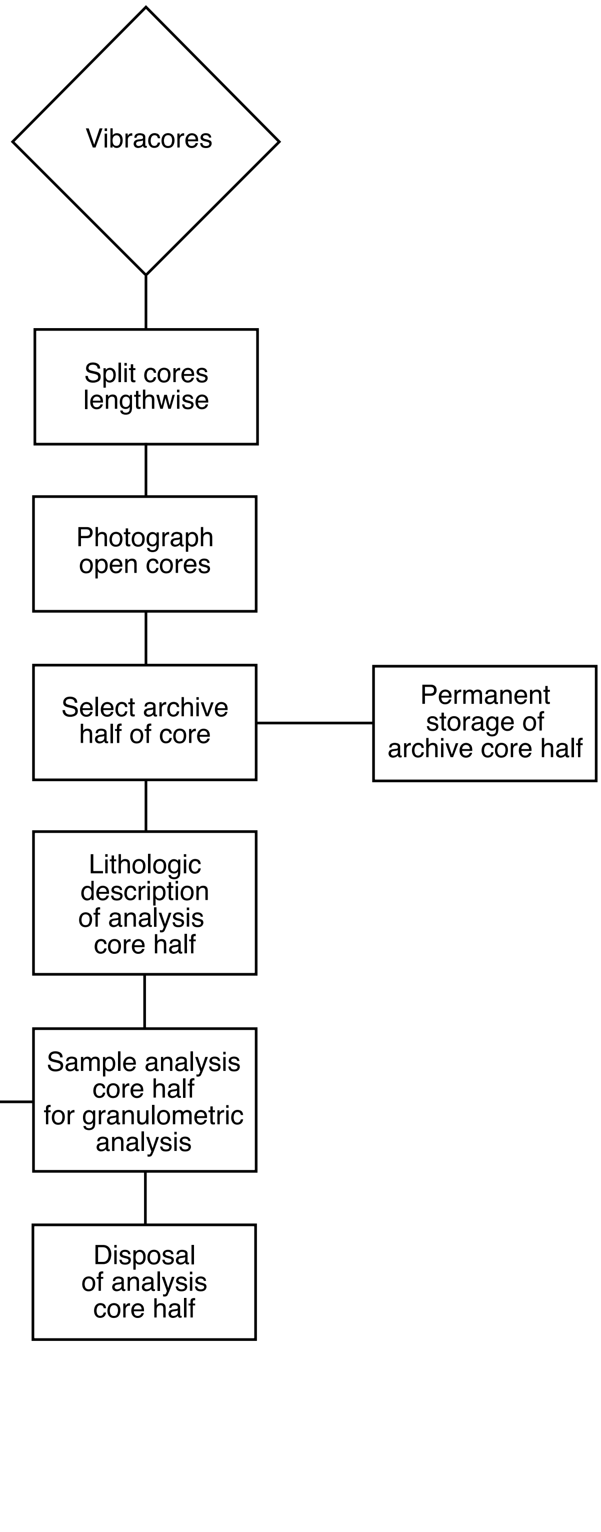


Figure 15.--Flow chart for the laboratory processing of vibracores.

Supplementary samples include lithologic samples (lithified zones and gravel), biological samples (shells), radiocarbon samples (wood, peat, and shells), and palynological samples (peat, roots, and rhizomes).

It was found that the physical and chemical properties of the clay minerals in the borings were altered due to oxidation, dehydration, chemical reactions between connate seawater and clay minerals, anaerobic bacterial activity, and chemical reaction between the aluminum core barrel and enclosing sediments. In addition, all of the boring samples were stored at ambient air temperature which caused extensive mold and mildew growth. Particle size analysis by hydrometer conducted on fine-grained samples would therefore result in inaccurate measurements. Grain-size characteristics of fine-grained sediment samples was determined by microscopic examination.

Coarse-grained samples from borings suffered from mold and mildew growth, semilithification due to chemical reaction between connate marine water and steel tops of sample containers, and improper subsampling techniques by previous researchers. Particle-size characteristics of these coarse-grained sediment samples were determined by microscopic examination.

Granulometric analysis of the 35 seafloor sediment samples and 521 vibracore sediment subsamples normally would be conducted by hydrometer and dry sieving (see Hummell and Parker, 1995a, b). However, lack of resources required that the sediment texture of these samples be determined by microscopic examination.

Lithofacies were defined for each sedimentary unit using grain size data, sediment texture, and other lithologic characteristics following Hummell (1996). The stratigraphic distribution of each lithofacies was determined by construction of a series of cross sections, tables and sediment distribution maps.

ANALYSIS

GEOMORPHOLOGY

Sedimentary deposits preserved in present-day Mobile Bay and Mississippi Sound record Holocene sea-level rise over the last 6,000 to 7,000 years (Hummell and Parker, 1995a, b). The preserved sedimentary record of the earlier Holocene transgressive history of coastal Alabama would be located on the continental shelf. Radiometric dates and sea level curves from Hummell (1996) indicate that the study area was inundated by the Holocene transgressing sea beginning about10,000 to 9,000 years before present.

The results of this study have shown that the physical aspects of the east Alabama inner continental shelf have changed substantially over the last 10,000 years. Prior to Holocene transgressive inundation, the area that is the present-day Alabama inner continental shelf was mostly occupied by marsh, coastal-plain terrestrial forests, and fluvial-deltaic systems (Hummell, 1996). Topographic relief in the study area was low except along the present-day Gulf of Mexico shoreline and shoreface zone of Morgan Peninsula. It is possible that an escarpment has been present along the Mississippi-Alabama barrier island system since at least the Pleistocene (Smith, 1988). As a result a prominent slope probably existed separating the gently sloping terrane of the study area from that of the area occupied by present-day Mobile Bay.

The generally low relief of the study area probably allowed the shoreline to transgress rapidly across the land surface (Smith 1986, 1988; Hummell, 1996). Holocene transgression caused the ancestral Perdido and Mobile-Tensaw fluvial-deltaic systems to migrate through the study area and into what is now Perdido Bay and Mobile Bay, respectively (Hummell and Parker, 1995b). The transgressing seas reworked and redistributed terrigenous sediment on the shelf through wave action and coastal currents, partially or completely destroying pre-Holocene geomorphologic features (Ludwick, 1964; Kindinger and others, 1982; Kindinger, 1988; McBride, 1997). Sediment directly underlying the Holocene cover on the Alabama inner continental shelf are composed mostly of relict fluvial-deltaic sediment deposited during the latest sea-level lowstand which ended about 15,000 to 18,000 years before present (Smith, 1988; Lockwood and McGregor, 1988).

During Holocene transgressive inundation of the study area and until the late stages of inundation of present-day Mobile Bay, the eastern half of present-day Morgan Peninsula existed as a peninsula and much of the western half probably existed as an emergent barrier island (Hummell and Parker, 1995b).

The ebb-tidal delta of Mobile Bay appears to have developed late in the inundation history of the Alabama inner continental shelf (Hummell, 1996). Formation of the longshore drift system along the southern margin of Morgan Peninsula and Dauphin Island, and a decrease in the rate of sea level rise about 4,500 years before present, not only facilitated barrier island development, but probably initiated ebb-tidal delta growth at the mouth of Mobile Bay (Hummell, 1996). A north-south oriented paleobathymetric high extending south from Pelican Point and the Mobile-Tensaw alluvial valley seems to have confined most of the growth of the ebb-tidal delta to the western side of Main Pass and south of Dauphin Island (Hummell, 1996). Ebb-tidal delta growth by vertical accretion and progradation continued throughout the late Holocene (Hummell, 1996).

GEOLOGY AND GEOLOGIC HISTORY

Upper Cenozoic sediment of the Alabama continental shelf consists of fluvial, fluvial-deltaic, estuarine, and coastal deposits of Pleistocene and Holocene age (Carlston, 1950). Quaternary development of the offshore Alabama continental shelf is related to multiple transgressions and regressions of the sea caused by worldwide changes in glacial-eustatic sea-level fluctuations (Ludwick, 1964; Kindinger and others, 1982; Suter and others, 1985; Kindinger, 1988; McFarlan and LeRoy, 1988; Kindinger and others, 1989; McBride, 1997).

Present-day offshore Alabama continental shelf seafloor topography and sediment distribution are the result of a combination of deltaic progradation, regression with concomitant dissection of the exposed shelf by ancient fluvial systems associated with the late Wisconsian sea-level fall, and reworking by coastal processes during Holocene sea-level rise (Ludwick, 1964; Kindinger and others, 1982; Kindinger, 1988; Kindinger and others, 1994; McBride, 1997). During late-Wisconsinian continental-glaciation sea-level falls, fluvial systems were incised into the continental shelf, and nearshore environments were extended seaward, ultimately culminating in the progradation of deltas at the seaward margin (Suter and others, 1985; Kindinger and others, 1989, 1994).

During regression associated with the late-Wisconsian sea-level fall, Mesozoic and Cenozoic Gulf Coastal Plain sediment was exposed on the shelf and eroded by fluvial systems that developed on the broad, low-lying plain (Kindinger and others, 1989). Marine, coastal, and fluvial environments prograded seaward until the sea-level reached a maximum lowstand which was about 400 feet below its present level (Milliman and Emery, 1968).

During Holocene sea-level rise beginning 15,000 to 18,000 years before present, fluvial-deltaic lowstand deposits were reworked, winnowing out much of the finer material. During transgression, fluvial systems were submerged and filled, and eventually a sea-level highstand was reached (Suter and others, 1985; Kindinger and others, 1989). Coleman and others (1990) suggest that the transgression is continuing today. Sediments underlying the thin Holocene sedimentary cover consist of relict or "palimpsest" (Swift, 1976) fluvial sands and gravels that were deposited during the latest low sea-level stand which ended about 18,000 years before present (Smith, 1986; Lockwood and McGregor, 1988).

Vibracores, borings, drill holes, and radiometric age dates of organic remains collected from the west Alabama inner continental shelf by Hummell (1996) and for this study reveal a Holocene transgressive marine and fluvial-deltaic fill sequence overlying estuarine and fluvial-deltaic deposits of at least in part Pleistocene age. A southward dipping, late Pleistocene-early Holocene disconformity (last transgressive surface) was formed by erosion of pre-Holocene estuarine and fluvial-deltaic deposits during late Pleistocene and early Holocene regression and sea-level lowstand. This disconformity extends throughout Mobile Bay and Mississippi Sound

(Hummell and Parker, 1995a, b) and the Alabama inner continental shelf (Hummell, 1996; McBride, 1997). Subsequently, roughly north-south oriented networks of channels were incised into these deposits south of present day Dauphin Island (ancestral Escatawpa fluvial-deltaic system) and Morgan Peninsula (Mobile-Tensaw and Perdido fluvial-deltaic systems) (Hummell and Parker, 1995a, b; Hummell, 1996). The Holocene sequence is thickest in the ebb ramp of the ebb-tidal delta of Mobile Bay and in the incised paleochannels (Hummell, 1996).

Transgressive flooding of the east Alabama inner continental shelf between 10,000 and 6,000 years before present caused marine, estuarine, fluvial-deltaic, and ebb-tidal delta sediments to be deposited over pre-Holocene estuarine and fluvial-deltaic deposits (Hummell, 1996). With the decrease in the rate of sea level rise about 4,500 years before present the shoreline stood a few miles seaward of the present day shoreline (Hummell, 1996). The decrease in the rate of sea level rise and the formation of the longshore drift system along the southern margin of Dauphin Island and Morgan Peninsula caused late Holocene barrier island development through vertical accretion and initiated and promoted ebb-tidal delta growth through vertical accretion and progradation (Hummell, 1995b; Hummell, 1996).

Sea level rise resulting in flooding of the remainder of the present day east Alabama inner continental shelf fostered deposition of mostly marine and ebb-tidal delta sediment. This continued uninterrupted throughout the late Holocene and continues today.

LITHOFACIES

The study area contains nine Holocene and one pre-Holocene lithofacies; each representing one or more depositional environments. Lithofacies were grouped together into depositional settings. This report follows the lithofacies classification scheme of Hummell (1996).

The lithofacies defined for the study area include shelf mud, surficial sand sheet, ebb-tidal delta (undifferentiated), delta front, channel sand, peat, marsh, levee, interdistributary bay, and pre-Holocene. Figure 16 is a generalized stratigraphic sequence for the east Alabama inner

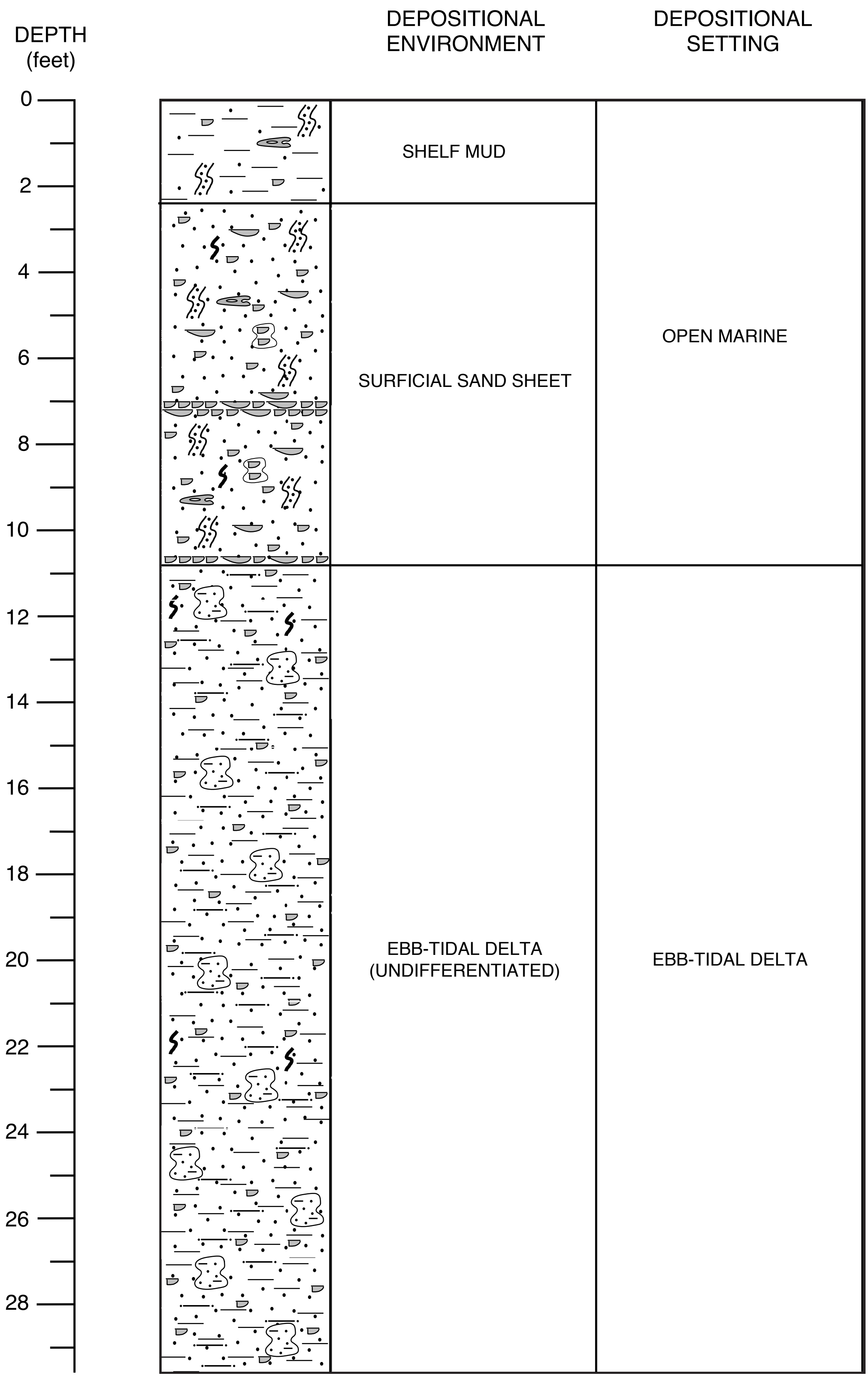


Figure 16.--Generalized stratigraphic sequence of the east Alabama inner continental shelf.

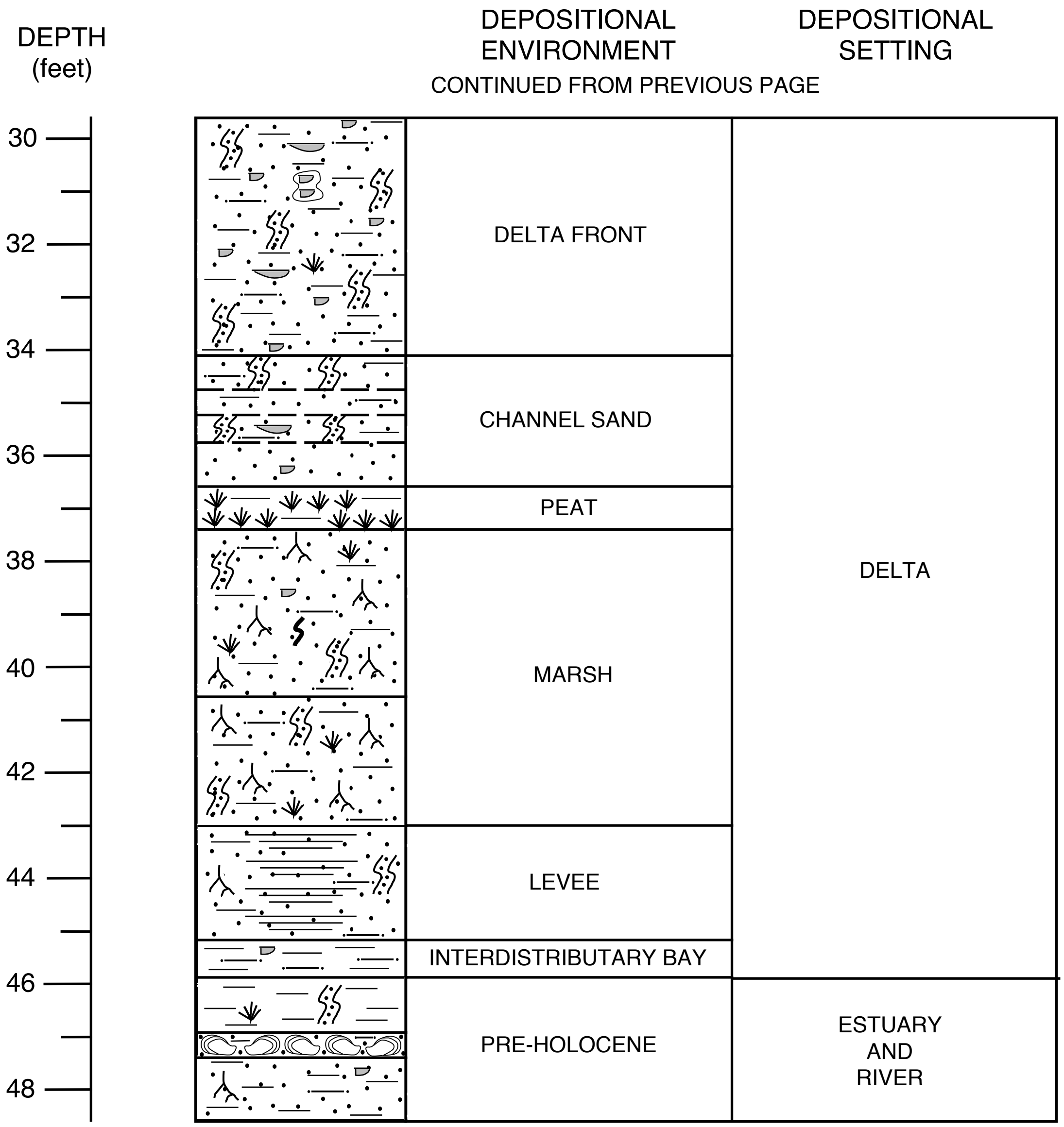


Figure 16.--Generalized stratigraphic sequence of the east Alabama inner continental shelf--Continued.

continental shelf study area showing the lithofacies, depositional environments, and depositional settings. Table 4 displays the distribution of lithofacies thickness by foundation boring and vibracore, and percentage occurrence of each lithofacies. Lithofacies distribution at the seafloor is shown in figure 17.

SHELF MUD LITHOFACIES

Shelf mud (Hummell, 1996) currently occupies one vibracore site, located near the southern boundary of sand resource area 3 (fig. 17). Hummell (1996) discusses at length the shelf mud lithofacies and its relationship to the open bay lithofacies. Shelf mud occurs when fine-grained sediment plumes, emanating primarily from Mobile Bay, move out on to the Alabama inner continental shelf and are entrained by longshore drift. Much of the plume-suspended sediment is eventually deposited on the continental shelf down drift of the ebb-tidal delta of Mobile Bay and in federal waters south of Main Pass (Hummell, 1996). The plume entrained fine-grained sediment is commonly reworked estuary mud (open bay lithofacies), but also can be suspended sediment transported by the Mobile-Tensaw or Perdido River systems. The two lithofacies are genetically related and in many cases are difficult to distinguish lithologically. Shelf mud and open bay lithofacies are most readily distinguishable by the associated lithofacies, bed geomorphology and lateral continuity, and preserved invertebrate fauna. Much of the plume activity, and therefore shelf mud deposits, lie southwest of Main Pass on the west Alabama inner continental shelf.

In the study area, the two lithologic units interpreted as shelf mud lithofacies average 2.4 ft thick. The shelf mud beds are a clay or sandy mud which overlay and grade laterally into deposits interpreted as surficial sand sheet lithofacies. The contacts between the shelf mud beds and surficial sand sheet beds within the vibracores are sharp. The shelf mud beds are bioturbated, containing sand-filled and muddy sand-filled burrows. The bioturbation results in the destruction of any primary sedimentary structures. Clay is the dominant constituent of the shelf mud beds and

Table 4.--Lithofacies distribution by foundation boring and vibracore

Lithofacies	Boring and vibracore number					
	Exxon 84-1115 B-1	Exxon 85-1071 B-1	Exxon 85-1072 B-1	Exxon 0183-3144 B-1	Exxon 0201-1071-1 B-1	Exxon 1188-1314 B-III-7
surficial sand sheet	8.8	14	16		26	18
shelf mud						
ebb-tidal delta	35.2	14	20	21	18	13
delta front						
channel sand						
marsh						
levee						
interdistributary bay						
peat						
delta front/levee undifferentiated						
levee/marsh undifferentiated						

Table 4.--Lithofacies distribution by foundation boring and vibracore--Continued

Lithofacies	Boring and vibracore number															
	Exxon 1188-1314 B-D-2 and 2A	G-6	G-7	G-8	G-9	G-10	G-11	G-12	G-13	G-14	G-15	SR-1	SR-2	SR-3	SR-4	SR-5
surficial sand sheet		2	3.3	4.1	5.8	5.3	3.2	2.7	3.3	3	3.2	4	6.1	7.8	9.4	16.5
shelf mud														0.4		
ebb-tidal delta	24.5											6.1				
delta front																
channel sand																
marsh																
levee																
interdistributary bay																
peat																
delta front/levee undifferentiated																
levee/marsh undifferentiated																

Table 4.--Lithofacies distribution by foundation boring and vibracore--Continued

Lithofacies	Boring and vibracore number																	
	SR-6	SR-7	SR-8	SR-9	SR-10	SR-11	SR-12	SR-14	SR-15	SR-16	SR-17	SR-18	SR-19	SR-20	SR-21	SR-22	SR-23	SR-24
surficial sand sheet	10.6	8.1	12	3.6	19	10.8	17.7	8.4		8.2	8.5	14.4		16.3	1.8	6.1	8.7	7.2
shelf mud									4.4									
ebb-tidal delta																		
delta front	4.4		5.4			1.5							9.9		0.5			
channel sand			0.7															
marsh																		
levee																		
interdistributary bay																		
peat																		
delta front/levee undifferentiated																		
levee/marsh undifferentiated																		

Table 4.--Lithofacies distribution by foundation boring and vibracore--Continued

	Boring and vibracore number																	
Lithofacies	SR-25	SR-26	SR-27	SR-28	SR-29	SR-30	SR-31	SR-32	SR-33	SR-34	SR-35	SR-36	SR-37	SR-38	SR-39	SR-40	SR-41	SR-42
surficial sand sheet	17	10.1		8.1	6.7	2.9	1.1	6.1	0.4	12.1	12.4	5.9	11.3	15	8.3	12.3	7.7	4
shelf mud																		
ebb-tidal delta																		
delta front			0.5					0.3							4.5			
channel sand																		
marsh														0.7				
levee			1.2											0.8			1	
interdistributary bay																0.6		
peat	0.8																	
delta front/levee undifferentiated																4.4		
levee/marsh undifferentiated																		

Table 4.--Lithofacies distribution by foundation boring and vibracore--Continued

	Boring and vibracore number																	
Lithofacies	SR-43	SR-44	SR-45	SR-90	SR-91	SR-92	SR-93	SR-94	SR-95	SR-96	SR-97	SR-98	SR-99	SR-100	SR-101	SR-102	SR-103	SR-104
surficial sand sheet	6.3	6	12.4	9.2			14.3	5.8	10.6	3	2.5	11.1	9.8	12.4	4.3	1.6	13.2	2.2
shelf mud																		
ebb-tidal delta					17.6													
delta front	3					14.8									1.3			4.5
channel sand																5.8		
marsh								3.6		2.6	13			0.4	9	8.4		
levee														0.8	2.6			6.7
interdistributary bay			0.7															
peat																		
delta front/levee undifferentiated			4.7															
levee/marsh undifferentiated								5.1										

Table 4.--Lithofacies distribution by foundation boring and vibracore--Continued

	Boring and vibracore number															Total	Percent of
Lithofacies	SR-105	SR-106	SR-107	SR-108	SR-109	SR-110	SR-111	SR-112	SR-113	SR-114	SR-115	SR-116	SR-117	SR-118	SR-119	length in feet	total core length
surficial sand sheet	0.9	12.5	14.1	4.1	13.9	5.9	6.6	2.5	8.6	2.2	0.6	1.7	9.9	12.2	14	709.6	65.9
shelf mud																4.8	0.4
ebb-tidal delta																169.4	15.7
delta front	3.8			9.2		2.7	0.6	2.2		9.2	10.3	3.8	0.4	5.4		98.2	9.1
channel sand	2.1			0.8		2.8		2.9								15.1	1.4
marsh	7											5.5				50.2	4.7
levee																13.1	1.2
interdistributary bay																1.3	0.1
peat																0.8	0.1
delta front/levee undifferentiated																9.1	0.8
levee/marsh undifferentiated																5.1	0.5

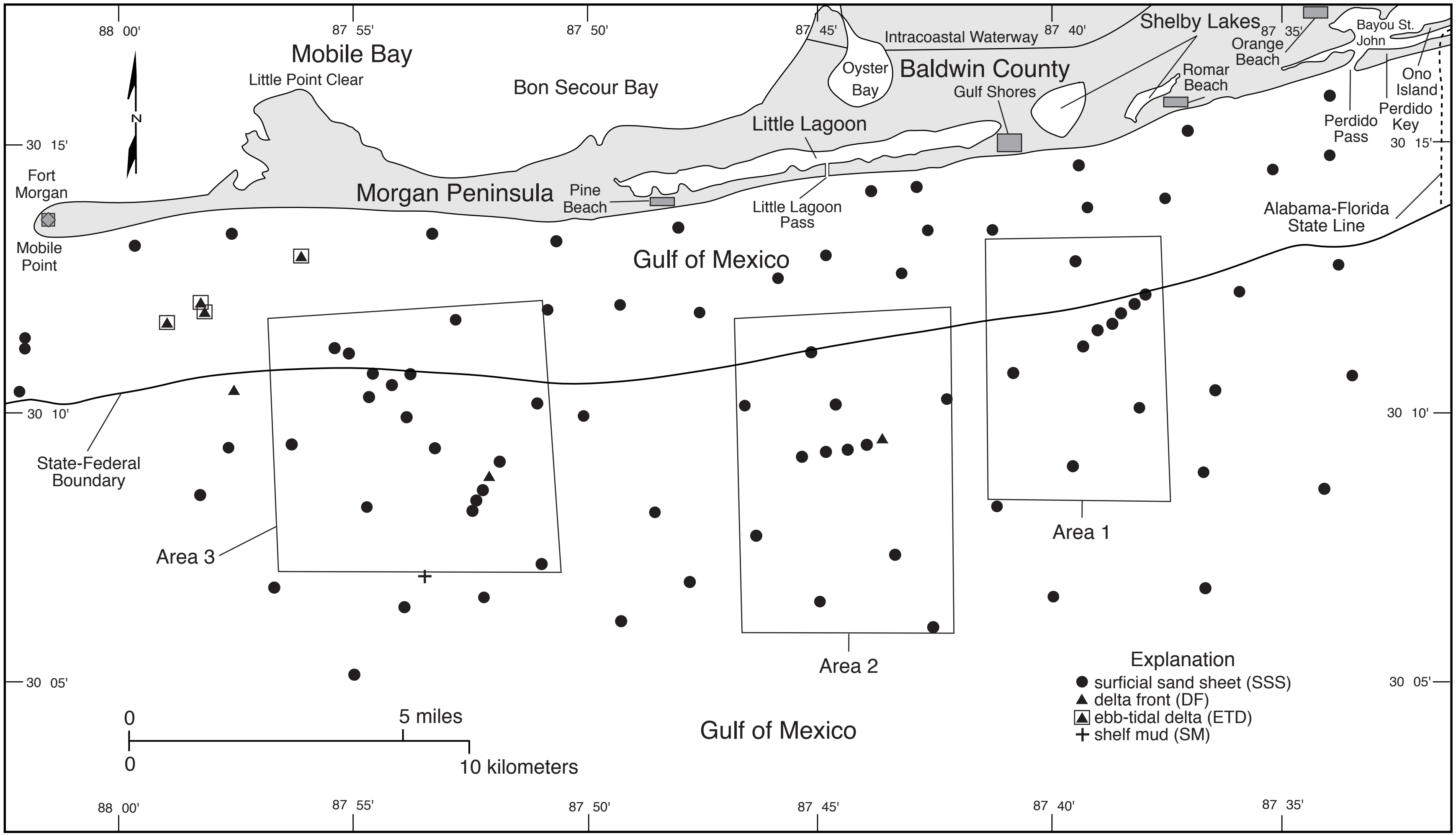


Figure 17.--Surface lithofacies distribution in the east Alabama inner continental shelf study area.

the sorting is poor. In places gravel-sized whole mollusc shells and shell fragments are common within the shelf mud beds.

SURFICIAL SAND SHEET LITHOFACIES

Geographically, sediment interpreted as surficial sand sheet lithofacies (SSS) (McBride and others, 1991; Hummell, 1996) are the most extensive in the study area. The SSS lithofaces typically overlies ebb-tidal delta or delta front lithofacies deposits in stratigraphic sequence and is presently distributed everywhere within the study area with the exception of portions of the ebb-tidal delta of Mobile Bay (fig. 17). The SSS lithofacies sediments may overlie ebb-tidal delta, delta front, marsh, levee, and pre-Holocene lithofacies deposits. Beds interpreted as SSS lithofacies average 8.4 ft thick, range in thickness from 0.4 to 26 ft, and reach their maximun thickness on the swash platform east of the Mobile-Tensaw alluvial valley (western edge of the study area) and in paleochannels. Even though penetration was very good, wave compaction and the coarse texture of the SSS lithofacies still caused a number of the vibracores to fail to penetrate the SSS lithofacies deposits, so the true thickness of the lithofacies in these vibracores is unknown in several localities.

The SSS lithofacies sediments interfinger with ebb-tidal delta, delta front, and shelf mud deposits. The depositional environment of the SSS lithofacies represents widespread deposition of reworked palimpsest clean sands following Holocene transgression (Johnson, 1978; Ludwick, 1964; Parker and others, 1997). However, the SSS lithofacies was initially formed from continental shelf deposits reworked and redistributed by marine processes during Holocene transgression (Suter and others, 1985; Kindinger and others, 1989).

The SSS lithofacies deposits are widespread, massive, and take on a sheet-like geometry (Hummell, 1996). Shallow water and high wave energy promotes a sheet over ridge geometry. Embedded in the SSS lithofacies are shelf sand ridges and transverse bars. The ridges are capped by mobile sands or coarse-grained sediments that are moved by storms and interstorm shelf currents (Parker and others, 1997). The inter-ridge troughs are the site of much quieter water deposition of fines between storms, and may receive coarse washovers during storms.

On the east Alabama inner continental shelf, sediments that are interpreted as SSS lithofacies consist of sand. The SSS lithofacies deposits are generally unstructured, but horizons within beds do occur that consist of thinly laminated sand and shelly sand or gravel to sand-sized shell hash. Commonly the deposits fine upward. There may be a decrease upward in grain size, or abundance or size of shells and shell fragments. The fining upward sediment texture commonly is due to a combination of these factors. The fining upward sequences by and large represent storm deposits, and in a few instances shelf sand ridges. Commonly, the SSS lithofacies deposits contain more than one storm cycle. The graded nature, sharp base, and variable thickness of the deposits are typical of tempestites (Aigner, 1985). Muddy sand pockets are rare. Bioturbation is less intense than other lithofacies with a bioturbation index averaging 2. Muddy sand-filled and mud-filled burrows are common in SSS lithofacies deposits. Whole shells and shell fragments occur abundantly throughout the SSS lithofacies beds. Wood fragments and plant material are rare in SSS lithofacies sediments.

EBB-TIDAL DELTA LITHOFACIES

Main Pass is classified as an ebb-type tidal inlet because of the presence of a prominent ebb-tidal delta seaward of the inlet (Hubbard and others, 1979). In addition, Main Pass would be classified as tide-dominated due to its well-developed ebb-tidal delta, poorly developed flood-tidal delta, and deep central channel through which tidal currents flow flanked by channel margin bars (Pelican Island and associated submerged shoals) (Hubbard and others, 1979) (fig. 3). Although ebb-tidal deltas are common along barrier island coasts of the Gulf of Mexico and western Atlantic, their sedimentary processes, stratigraphy, and facies are not well understood. The internal structure of the deltas results from the interaction between tidal currents and waves. Tidal deltas vary widely in their characteristics, due chiefly to the magnitude of the tidal range (Israel and others, 1987) and the types of depositional environments bordering the inlet (examples include lagoon or estuary).

Internally, the ebb-tidal delta of Mobile Bay comprises clay, silt, sand, and gravel, represented in a wide variety of sediment texture types. These sediment types are distributed in lensoid and tabular bodies of varying thickness and mostly limited lateral extent. Sedimentary deposits interpreted as open bay (see Hummell and Parker, 1995a, b; Hummell, 1996) and surficial sand sheet lithofacies extensively interfinger with ebb-tidal delta deposits. The lithologic and stratigraphic complexity results from the interplay between waves, tides, freshwater discharge events, shelf currents, and the variety of sediment grain-sizes available. The complex water circulation pattern produces shoals, sand waves, dunes, and ripples. This combination results in sediment texture heterogeneity in surficial sediment of the ebb-tidal delta and ultimately, sediment texture and bed geometry heterogeneity of the ebb-tidal delta sedimentary deposit.

Some researchers (Friedman and Sanders, 1978; Reineck and Singh, 1986; Sha, 1989) choose not to subdivide ebb-tidal delta deposits into lithofacies, while others have tried to group lithostratigraphic units into distal or proximal-tidal delta lithofacies (Hennessy and Zarillo, 1987; Israel and others, 1987). Many additional closely spaced vibracores and detailed granulometric analyses will be needed to adequately define ebb-tidal delta of Mobile Bay lithofacies and understand their genetic relationships. It is prudent at this juncture to group lithostratigraphic units under ebb-tidal delta lithofacies (undifferentiated) as Hummell (1996) did, rather than attempt to develop a set of lithofacies which in all probability would have to be revised once the necessary additional data are obtained.

Presently, sediments interpreted to be ebb-tidal delta lithofacies cover the sea bottom in a portion of the study area southwest of Little Point Clear (fig. 17). This lithofacies averages 18.8 ft thick and ranges in thickness from 6.1 to 35.2 ft. Holocene ebb-tidal delta lithofacies sediments are confined to the ebb-tidal delta, and interbed and interfinger with SSS and delta front lithofacies sediments. Similarities between ebb-tidal delta and delta front lithofacies make distinguishing the two lithofacies in the subsurface difficult. In the study area, beds identified as ebb-tidal delta lithofacies consist of clay, mud, sand, or a combination of these lithololologies. Beds contain few to abundant muddy sand pockets (mostly burrow fills). Mud- and sand-filled burrows are common and plant material is rare in the borings and vibracores. Ebb-tidal delta lithofacies deposits characteristically have abundant shell material. Occasionally, sand-sized muscovite is present as an accessory constituent.

The majority of ebb-tidal delta beds are devoid of primary sedimentary structures. However, some beds or horizons within beds are thinly laminated with mud, sandy clay, and muddy sand. The laminated sediments are probably produced by selectively depositing certain grain sizes of sediment in transport in accordance with fluctuating water velocities caused by tides, waves, freshwater discharge events, and migrating bedforms (Oertel, 1973).

The ebb-tidal delta contains molluscan-rich, muddy sand beds that can be laterally persistent. The preservation of articulated bivalves, abundance and pristine condition of the molluscan and echinoid hard parts, and development on the flanks of the ebb-tidal delta of Mobile Bay (in an area of active sedimentation associated with organic-rich sediment plumes emanating from Mobile Bay) demonstrate the high biological productivity of the ebb-tidal delta. Also, the slow winnowing of these beds by waves or currents produces a sand with an enhanced shelly concentration (Parker and others, 1997).

The depositional environment of the ebb-tidal delta lithofacies partly consists of older sediment that formed during Holocene transgression of the EEZ (Bridges, 1975). It may include restricted circulation (variable, lower salinity and water energy) deposits typical of bays and lagoons, including bay muds, silty sands, nearshore interbedded sands and muds, oyster reefs, and bay margin peat deposits (Parker and others, 1997; Hummell, 1996). Additionally, it may include mixed transitional mud and sand units formed on the open shelf during early stages of transgression (Parker and others, 1997).

Lithologic units interpreted as shelf mud and open bay lithofacies appear at the sediment-water interface and in the subsurface of the ebb-tidal delta of Mobile Bay (Hummell, 1996). At the surface and in the subsurface of the ebb-tidal delta in the west Alabama inner continental shelf, lithologic units of both lithofacies thin toward the southwest (Hummell, 1996). However, Holocene shelf mud and open bay lithofacies do not appear in the subsurface of the east Alabama inner continental shelf.

DELTA FRONT LITHOFACIES

The delta front lithofacies (Maldonado, 1975; Stephen and Gorsline, 1975; Reineck and Singh, 1986) is exposed at the seafloor in three locations scattered across the study area (fig. 17). In the study area, this lithofacies consists of interbedded sand, silty sand, and sand-silt-clay. Bedding thickness ranges from a few tenths of a foot to several feet. Contacts between beds can be sharp or gradational. Bioturbation is uniform within a given bed, but varies widely from bed to bed (bioturbation index 2-5). Mud-rimmed, sand-filled burrows and shells, shell fragments, and bioclastic debris are generally common, but again, abundance varies from bed to bed. Plant material is rare in study area delta front lithofacies deposits. Primary sedimentary structures include horizontal bedding. Shelly sand pockets (burrow fills) are scarce to common.

The delta front lithofacies is one of several preserved lithofacies of Holocene Mobile-Tensaw and Perdido fluvial-deltaic systems that once occupied the study area. These fluvial-deltaic deposits have been partly reworked by Holocene transgression. Paleochannels are largely filled or backfilled with delta front lithofacies deposits and it is in these paleochannels that the lithofacies is best preserved and reaches its greatest thickness. Average thickness of the lithofacies is about 4.5 ft with a range from 0.3 to 14.8 ft. The delta front lithofacies underlies the SSS lithofacies and can interfinger with it.

CHANNEL SAND LITHOFACIES

The channel sand lithofacies (Reineck and Singh, 1986) is not exposed at the seafloor in the study area. In the study area, this lithofacies occurs as paleochannel lag deposits of interbedded sand which are neither massive nor cross-stratified. Individual beds measure from a few tenths of a foot to about one foot in thickness. Contacts between beds are usually gradational. As with the delta front lithofacies, bioturbation is uniform within a given bed, but varies from bed to bed (bioturbation index 2-3). Mud-rimmed, sand-filled burrows are generally common, but plant material, shells, shell fragments, and bioclastic debris are scarce or rare. In some beds, shell fragments and bioclastic debris can be abundant. There are no visible primary sedimentary structures. The lithofacies averages 2.5 ft thick and ranges in thickness from 0.7 to 5.8 ft. The channel sand lithofacies underlies and interfingers with the delta front lithofacies.

MARSH AND PEAT LITHOFACIES

Several vibracores in the study area penetrate Holocene peat or root zones that are interpreted as marsh deposits (Kraft, 1971; Fletcher and others, 1990). Hummell and Parker (1995a, b) and Hummell (1996) have mapped Holocene and pre-Holocene marsh deposits throughout Mobile Bay, Mississippi Sound, and the west Alabama inner continental shelf. Marsh lithofacies are found along paleoshorelines and paleochannel margins, and in paleobackswamps of the Mobile-Tensaw and Escatawpa fluvial-deltaic systems. In the east Alabama inner continental study area, Holocene marsh lithofacies deposits occur along paleochannel margins of the Mobile-Tensaw and Perdido fluvial-deltaic systems. The lithofacies underlies SSS and delta front lithofacies and overlies levee deposits and the pre-Holocene.

Marsh lithofacies are peaty and rooted sand, silty sand, and sand-silt-clay beds where the organic and mud content imparts a dark gray (often greenish or bluish) color to the beds. The marsh lithofacies in the study area averages 5.6 ft thick and ranges from 0.4 to 13 ft thick. Marsh deposits are characterized by peat, roots, and wood fragments. Mud-rimmed, sand-filled burrows and clay pebbles are sometimes present. Sedimentary structures are limited to occasional horizons of thin laminations. Shells or shell material are rarely associated with any of the marsh deposits. In some cases, interbedded sequences of delta front and levee lithofacies or levee and marsh lithofacies could not be visually differentiated from one another. In these situations, the sequence is recorded as delta front and levee lithofacies (undifferentiated) or levee and marsh lithofacies (undifferentiated).

The sediment texture and color of the study area marshes differ from the Holocene and pre-Holocene marshes mapped in Mobile Bay and Mississippi Sound which were frequently developed on top of the late Pleistocene-early Holocene disconformity (Hummell and Parker, 1995a, b). The upper 3 ft or so of the pre-Holocene (with the exception of the pre-Holocene within the main paleochannels of fluvial-deltaic systems) is a paleosol, enriched with clay-sized mineral weathering products (Hummell and Parker, 1995a, b). In addition, the paleosol is mottled and variegated (Hummell and Parker, 1995a, b). By contrast, the Holocene marshes of the east Alabama inner continental shelf are developed on top of levees and other sand-rich Holocene fluvial-deltaic sediments or pre-Holocene estuary and fluvial deposits that have little paleosol development.

The marsh deposits of the study area are frequently comprised of multiple marshes stacked one above the other. These marsh cycles indicate fluvial flood events and changing sea level. Mobile Bay and Mississippi Sound Holocene and pre-Holocene marsh deposits commonly contain a rooted bed and an overlying peat bed (Hummell and Parker, 1995a, b). However, study area Holocene marsh rooted beds rarely are overlain by a peat bed.

Vibracore SR-25 (app. A-24) contains two peat beds that measure 0.4 ft thick each. Peat lithofacies deposits (Reineck and Singh, 1986; Hummell and Parker, 1995a, b) are composed of laminated or interbedded peat, clay, mud, and muddy sand. Wood fragments are commonly found within the peat beds. The peat beds in vibracore SR-25 are interbedded with SSS lithofacies.

The peat lithofacies formed in quiet marshy environments - either low salinity estuarine intertidal salt marshes or nonmarine palustrine wetlands (Cowardin and others, 1979). In coastal Alabama these Holocene-age peat deposits are associated with paleotopographic highs on the late Pleistocene-early Holocene disconformity (transgressive surface) (Hummell and Parker, 1995a, b; Hummell, 1996). The hypotheses that the peat beds are formed from either floating mats of plant material, burial of marsh plants by a flood event, or burial by rapid rise in sea level have been discussed by Hummell and Parker (1995a, b) and Hummell (1996).

LEVEE LITHOFACIES

The levee lithofacies (Cotter, 1975; Reineck and Singh, 1986) does not crop out at the seafloor in the study area. The lithofacies is comprised of interbedded sand, muddy sand, and sand-silt-clay beds that are very thin to thinly laminated. Bioturbation index varies from bed to bed, ranging from 2 to 5. Most beds contain scarce to common sand-filled burrows and roots. Pieces of wood and peat are occasionally present, but shells and shell fragments are rare. Bed contacts are sharp. In the study area, average thickness of levee lithofacies deposits are 2.2 ft. The deposits range from 0.8 to 6.7 ft thick. The levee lithofacies in the study area occurs along paleochannel margins associated primarily with Holocene marsh lithofacies deposits.

INTERDISTRIBUTARY BAY LITHOFACIES

The interdistributary bay lithofacies (Reineck and Singh, 1986) is rare in the study area and is not present at the seafloor. The lithofacies occurs in two vibracores collected and described by Parker and others (1997) and averages 0.7 ft thick. Study area interdistributary bay lithofacies beds consist of a shelly mud with an absence of primary sedimentary structures. Bed contacts are gradational. The lithofacies occurs between two Holocene paleochannels in the northeastern portion of the study area. There it is overlain by undifferentiated delta front and levee lithofacies.

PRE-HOLOCENE SEDIMENT

Sixteen vibracores and all borings from the study area penetrate what is interpreted as pre-Holocene sediment (Hummell and Parker, 1995a, b; Hummell, 1996; Parker and others, 1997). Pre-Holocene deposits are overlain directly by all Holocene lithofacies in the study area. However, these deposits are rarely overlain by SSS lithofacies. These vibracores and borings indicate that the pre-Holocene consists mostly of fluvial and estuarine sediments. The pre-Holocene is not exposed at the seafloor in the study area.

Criteria by Hummell and Parker (1995a, b) were used to identify the boundary between the pre-Holocene and Holocene in west Alabama inner continental shelf sediments (Hummell, 1996) and in the present study. The contact in the study area, which is interpreted as the late Pleistocene-early Holocene disconformity or main Holocene transgressive surface, correlates with the disconformity in Mobile Bay, Mississippi Sound, and west Alabama inner continental shelf. The pre-Holocene deposits that directly underlie the disconformity of the east Alabama inner continental shelf can be divided into three lithologies.

A stiff, gray or brown clay or mud containing sand-filled burrows and rare to common chalky shells and shell fragments is interpreted as open bay lithofacies (Hummell and Parker, 1995a, b). Some beds may be laminated. Pleistocene to Recent deposits of this estuarine lithofacies are found in Mobile Bay, Mississippi Sound, and the west Alabama inner continental shelf (Hummell and Parker, 1995a, b; Hummell, 1996). The majority of the pre-Holocene deposits penetrated by the study area vibracores and borings are open bay lithofacies. Some mud beds contain roots, peat, or wood fragments. These beds are interpreted as marsh lithofacies.

The Pleistocene oyster biostrome lithofacies (Hummell and Parker, 1995a, b) is represented in the study area by partially cemented, fabric supported in situ oysters in a sand-silt-clay matrix. Lithofacies deposits are olive gray in color. Some beds contain abundant oyster shell fragments indicating oyster biostrome talus deposits. The lithofacies was found on paleobathymetric highs and in shallow water areas of Mobile Bay and Mississippi Sound (Hummell and Parker, 1995a, b).

There are a variety of pre-Holocene sand and muddy sand beds found in the study area. In general, the beds contain scarce mud- or sand-filled burrows and shells and shell fragments. Primary sedimentary structures are limited to rare occurrences of lamination. Beds that contain roots and peat or wood are interpreted as marsh lithofacies. The sand beds are various shades of gray, brown, yellow, orange, and white. These pre-Holocene beds represent mostly estuarine depositional environments.

The late Pleistocene-early Holocene disconformity is identifiable in vibracores, borings, and on seismic records from Mobile Bay, Mississippi Sound, and the Alabama continental shelf. The pre-Holocene sediment in coastal Alabama generally displays characteristics of paleosols in the upper 3 ft of the deposit, indicating subaerial exposure. This oxidized zone is absent in the pre-Holocene sediments sampled by borings and vibracores collected within the Mobile-Tensaw alluvial system. Either water was always present in the alluvial valley thereby preventing subaerial exposure, or these sediments were quickly buried, thus avoiding significant weathering, or the oxidized zone was cut through and removed by fluvial activity as postulated by McFarlan and LeRoy (1988). The top of the pre-Holocene in Mobile Bay, Mississippi Sound, and the Alabama inner continental shelf shows evidence of being bored by marine organisms during flooding of the disconformity by Holocene transgression. This same disconformity and physical characteristics of the top of the pre-Holocene have been reported from Louisiana (McFarlan and LeRoy, 1988), Mississippi (Otvos, 1975), Alabama (Otvos, 1986; Hummell and Parker, 1995a, b; Hummell, 1996; McBride, 1997) and Florida (Davis and Klay, 1989; Donoghue, 1989).

Radiocarbon datable shells were obtained from the pre-Holocene oyster biostrome lithofacies sediments penetrated by the vibracores used in this study. Resources required to obtain radiocarbon dates for the shells were unavailable. In Mobile Bay and Mississippi Sound, radiometric dates determined from analysis of organic remains associated with the top of the pre-Holocene sampled by a few vibracores and borings indicate that the sediments directly below the disconformity in those cores are Pleistocene in age (Hummell, and Parker, 1995a, b). However, since there are so few radiometric dates available and other potentially dateable organic remains have not been found, it is not known if all sediments lying directly below the disconformity in Mobile Bay, Mississippi Sound, and the Alabama inner continental shelf are Pleistocene in age.

LITHOFACIES DISCUSSION

The lithofacies in the study area are diverse in their sedimentological characteristics and range from almost pure quartz sands (SSS lithofacies) to mud units (shelf mud lithofacies). Based on their composition, grain size, color, and visual aesthetics, some lithofacies would make appropriate beach replenishment materials, while others are unsuitable.

The SSS lithofacies would make an excellent source of beach nourishment sand for Morgan Peninsula Gulf of Mexico beaches. In general, sediment of this lithofacies contains less than 5 percent mud and a trace of heavy minerals. The sand-sized fraction averages medium to coarse sand, equal to or slightly coarser than the average grain size of Morgan Peninsula Gulf of Mexico beaches. The color of the sediment is white or gray. Microscopic examination of quartz grains from vibracore and boring samples shows that the color of the lithofacies is derived from the mud fraction. Removal of the mud by wave and swash activity on a nourished beach would change the sediment color to white within a short time after emplacement on beach shoreface. The SSS lithofacies vibracore and boring sediment samples show that the lithofacies maintains its lithologic homogeneity throughout the study area. The lithofacies is present in the study area as a massive sand sheet with associated shelf sand ridges and transverse bars. The upper surface of the sheet is exposed at the seafloor over 90 percent of the study area.

Alternative sources of beach nourishment sand could be obtained by recovering delta front and channel sand lithofacies. However, the relatively small volumes of sediment available, difficulty in physically accessing the deposits, and higher mud content (5 to 10 percent) make them less attractive sources of beach nourishment sand compared to the SSS lithofacies. However, in a sand recovery operation, where the target deposits are SSS lithofacies, the recovery of some delta front or channel sand lithofacies sediments would not pose a sand contamination problem.

The other lithofacies in the study area are judged to be inappropriate sources of beach nourishment sand because the sedimentary deposits of these lithofacies do not meet the criteria of composition, grain size, color, ease of recovery, and volume of material.

SPATIAL DISTRIBUTION OF LITHOFACIES

To make any sand recovery operation as cost-effective as possible, accurate description of surface and subsurface lithofacies geometry and overburden are essential. Figure 11 is a map of the distribution of surface sediment texture and figure 17 shows the distribution of surface lithofacies in the study area.

Twelve geologic cross sections were constructed through the study area showing the subsurface distribution of lithofacies. Figure 18 is a map that shows the locations of the cross sections through the study area. The cross section lettering scheme is a continuation of the cross section labeling of Hummell (1996) for the west Alabama inner continental shelf. The western endpoints of cross sections V-V''' and W-W''' (fig. 18) match the eastern endpoints of Hummell's (1996) cross sections Q-Q" and R-R", respectively. Three of the cross sections (figs. 19 through 26) are oriented east to west or about parallel to the prevailing strike direction of the Holocene and pre-Holocene deposits in the study area. Nine cross sections (figs. 27 through 35) are oriented north to south or about parallel to the prevailing dip direction of the Holocene and pre-Holocene deposits in the study area. These lithofacies are physically grouped in a Holocene age, transgressive sedimentary package and a pre-Holocene age sediment package separated by a time-transgressive, disconformity.

The twelve cross sections from the study area indicate that the late Pleistocene-early Holocene disconformity deepens toward the center of the Mobile-Tensaw and Perdido fluvial-

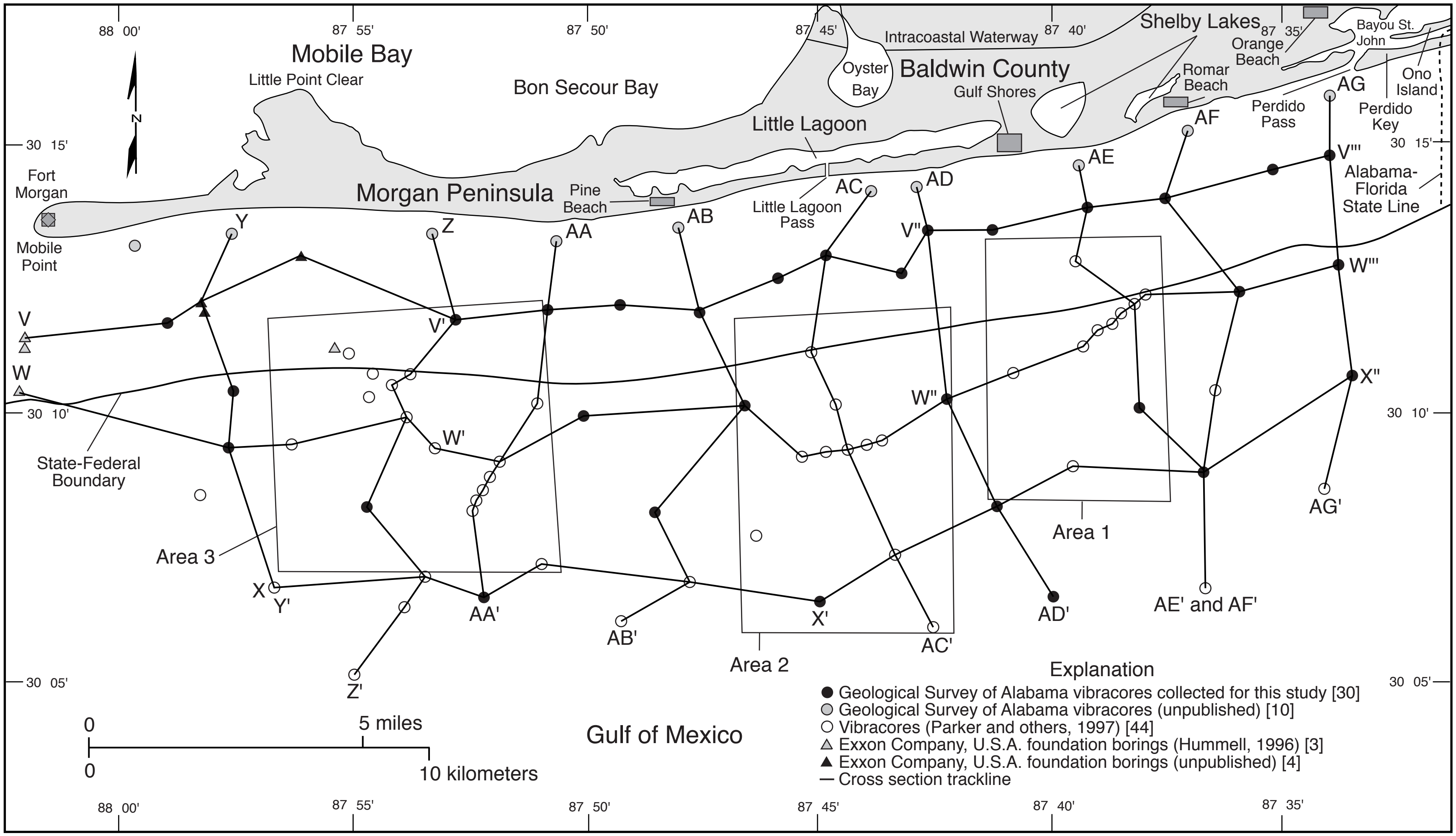


Figure 18.--Map showing locations of vibracores, foundation borings, and cross sections in the east Alabama inner continental shelf study area.

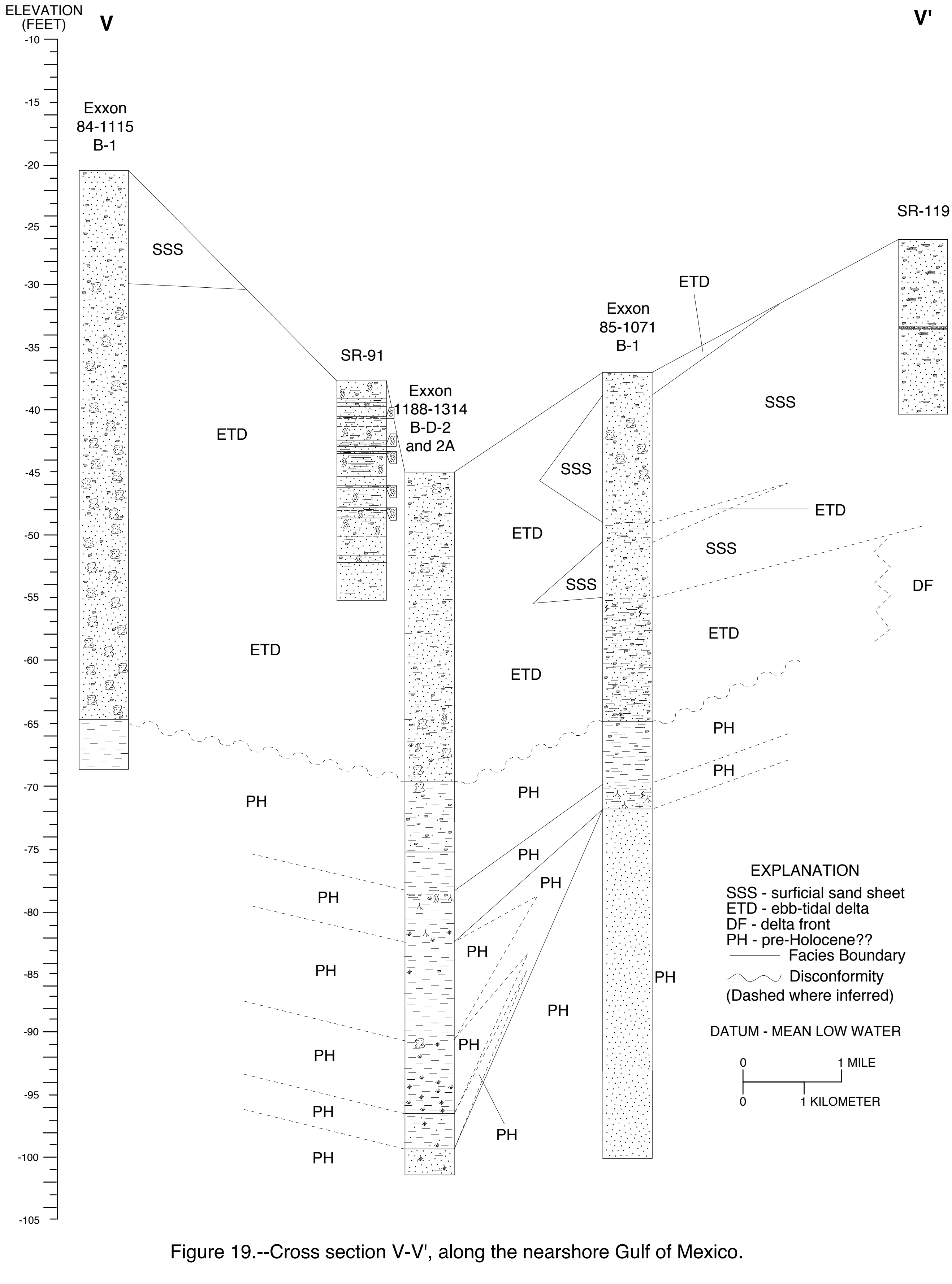


Figure 19.--Cross section V-V', along the nearshore Gulf of Mexico.

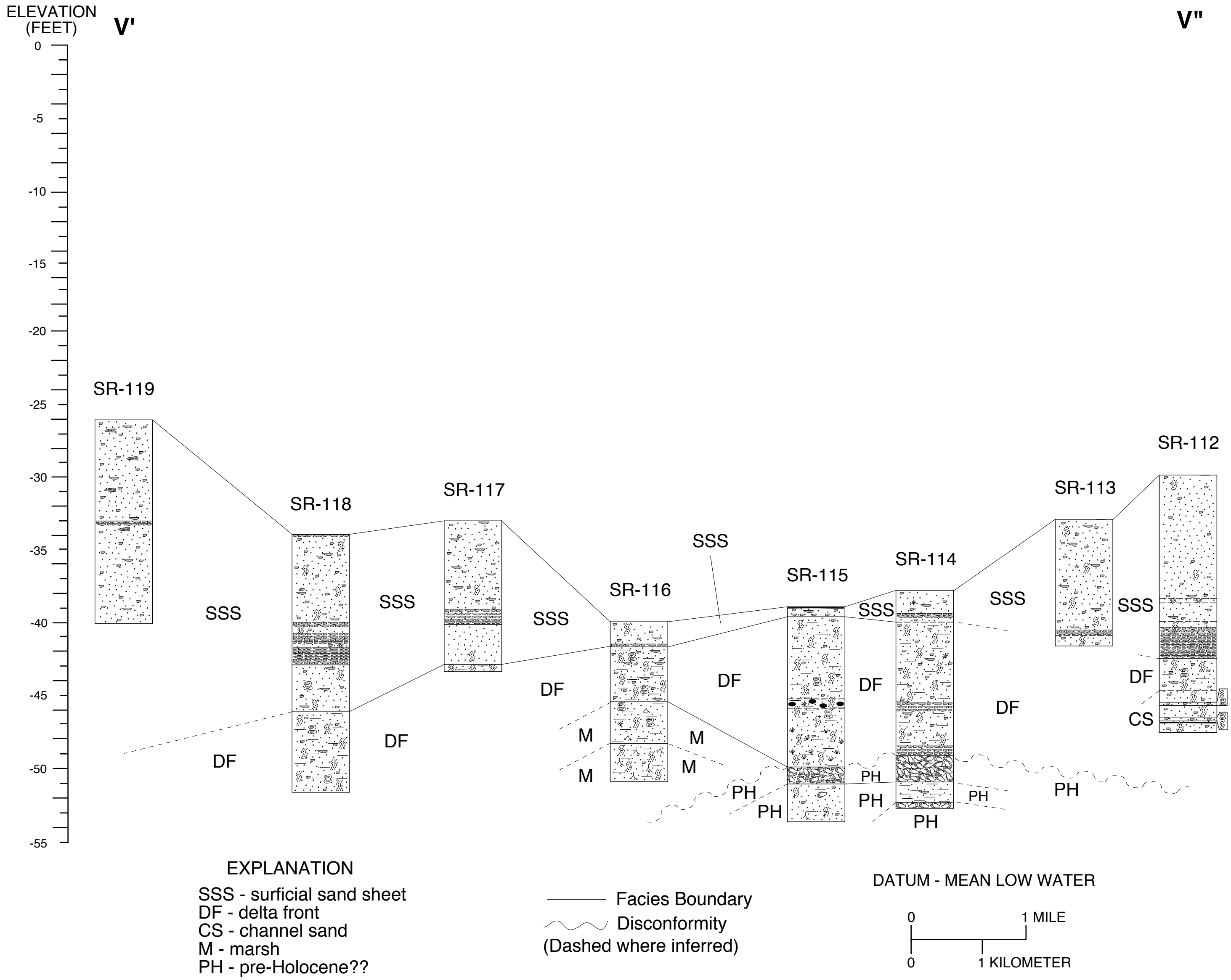


Figure 20.--Cross section V'-V", along the nearshore Gulf of Mexico.

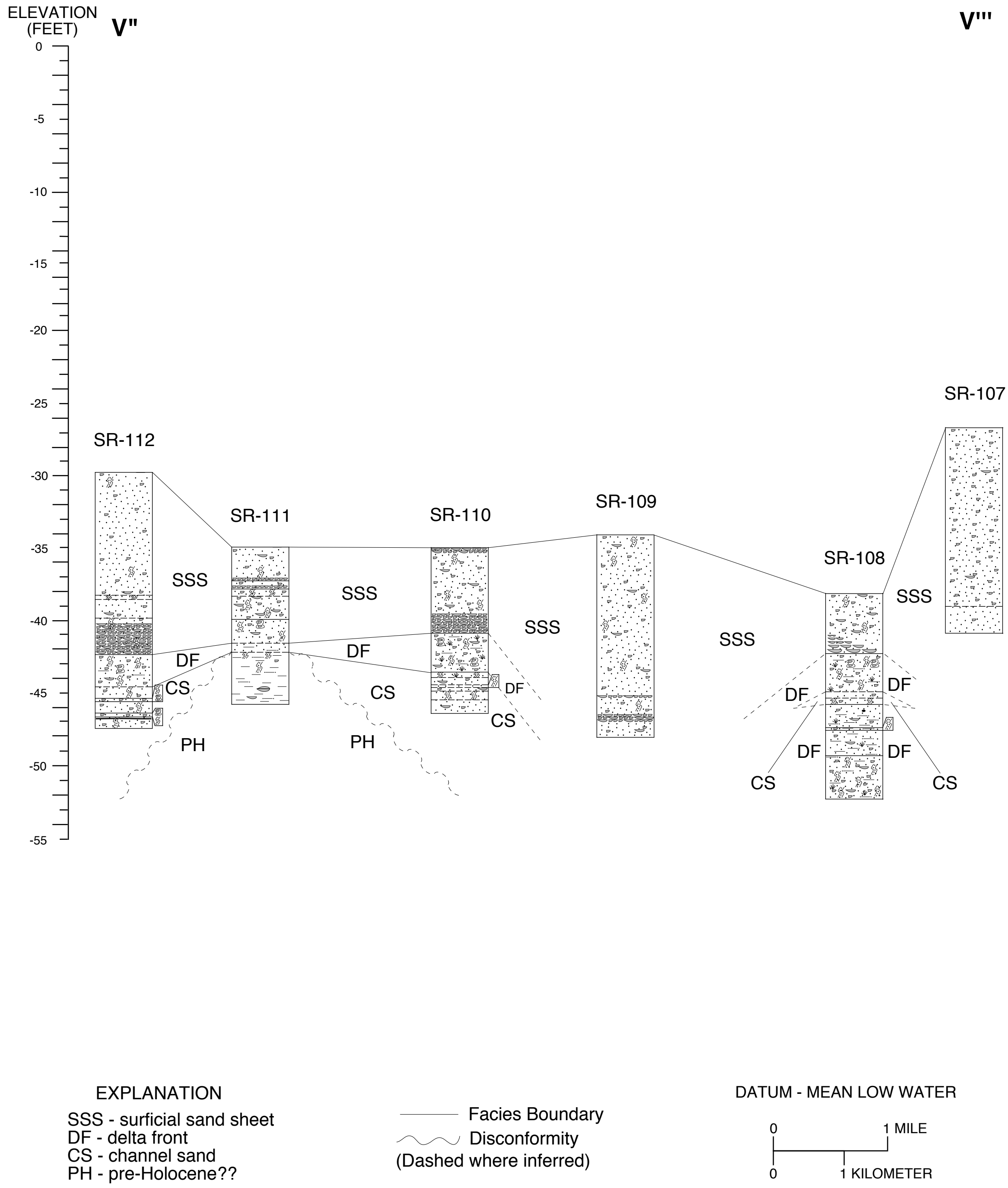


Figure 21.--Cross section V"-V''', along the nearshore Gulf of Mexico.

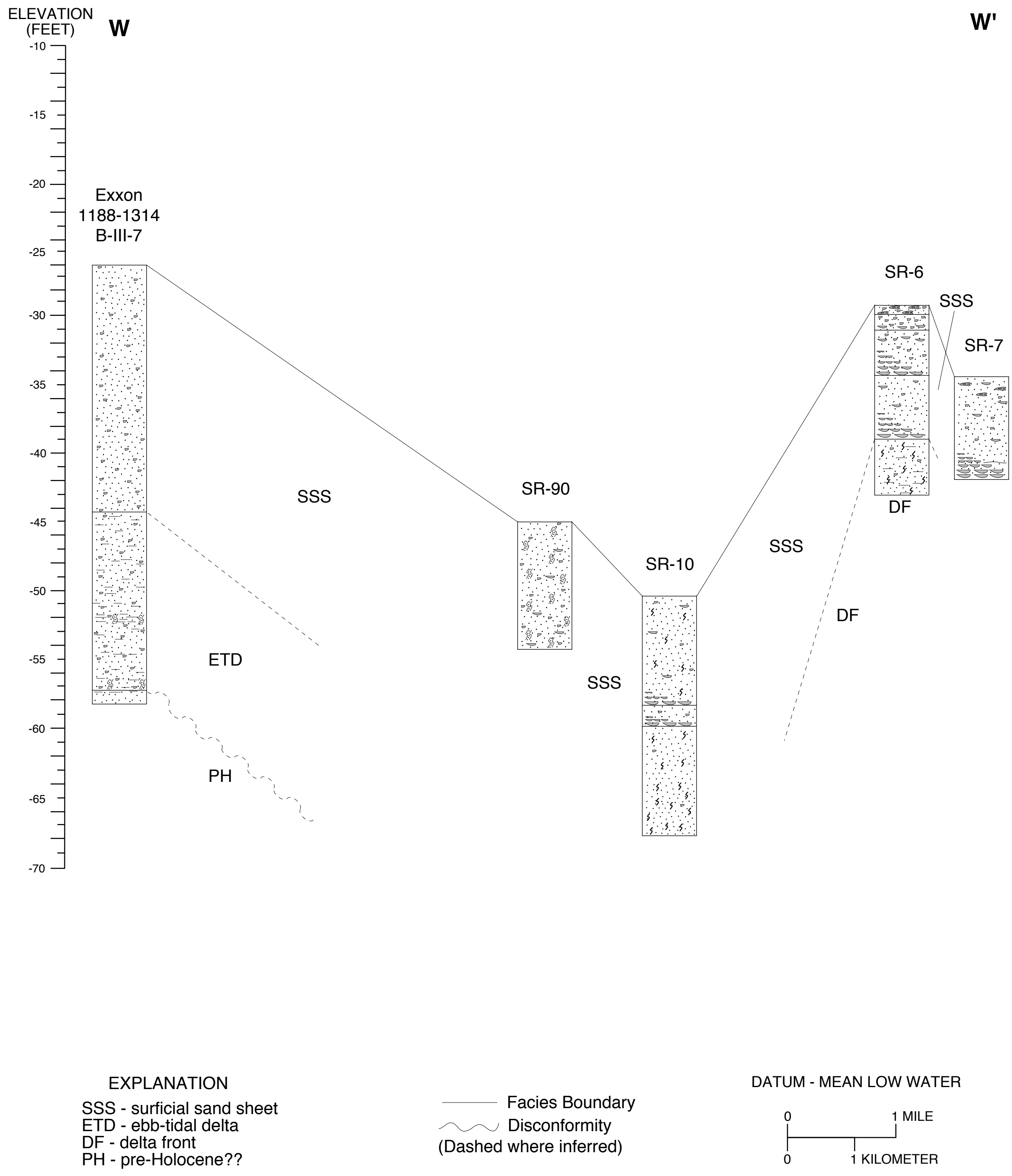


Figure 22.--Cross section W-W', along the nearshore Gulf of Mexico.

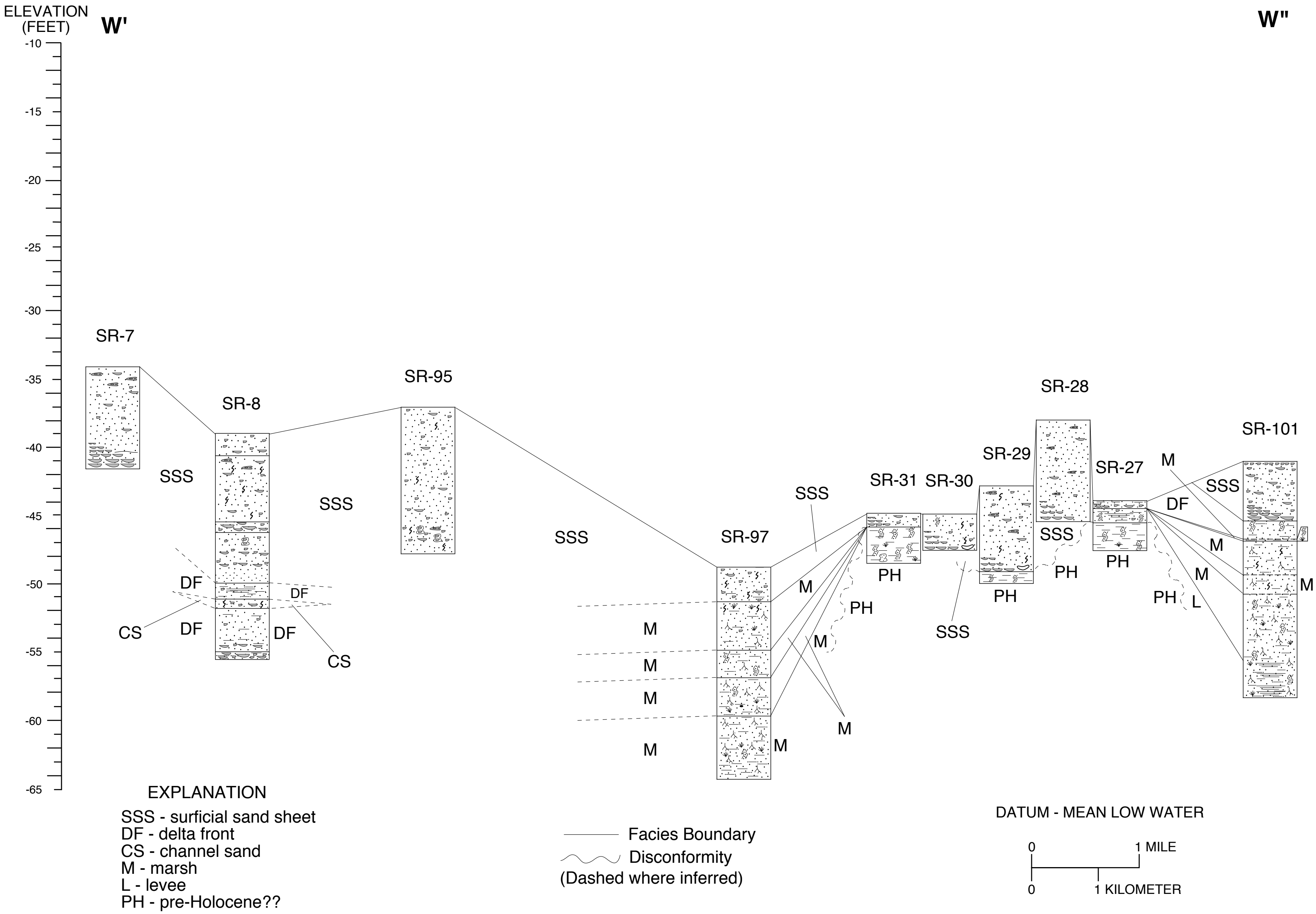


Figure 23.--Cross section W'-W", along the nearshore Gulf of Mexico.

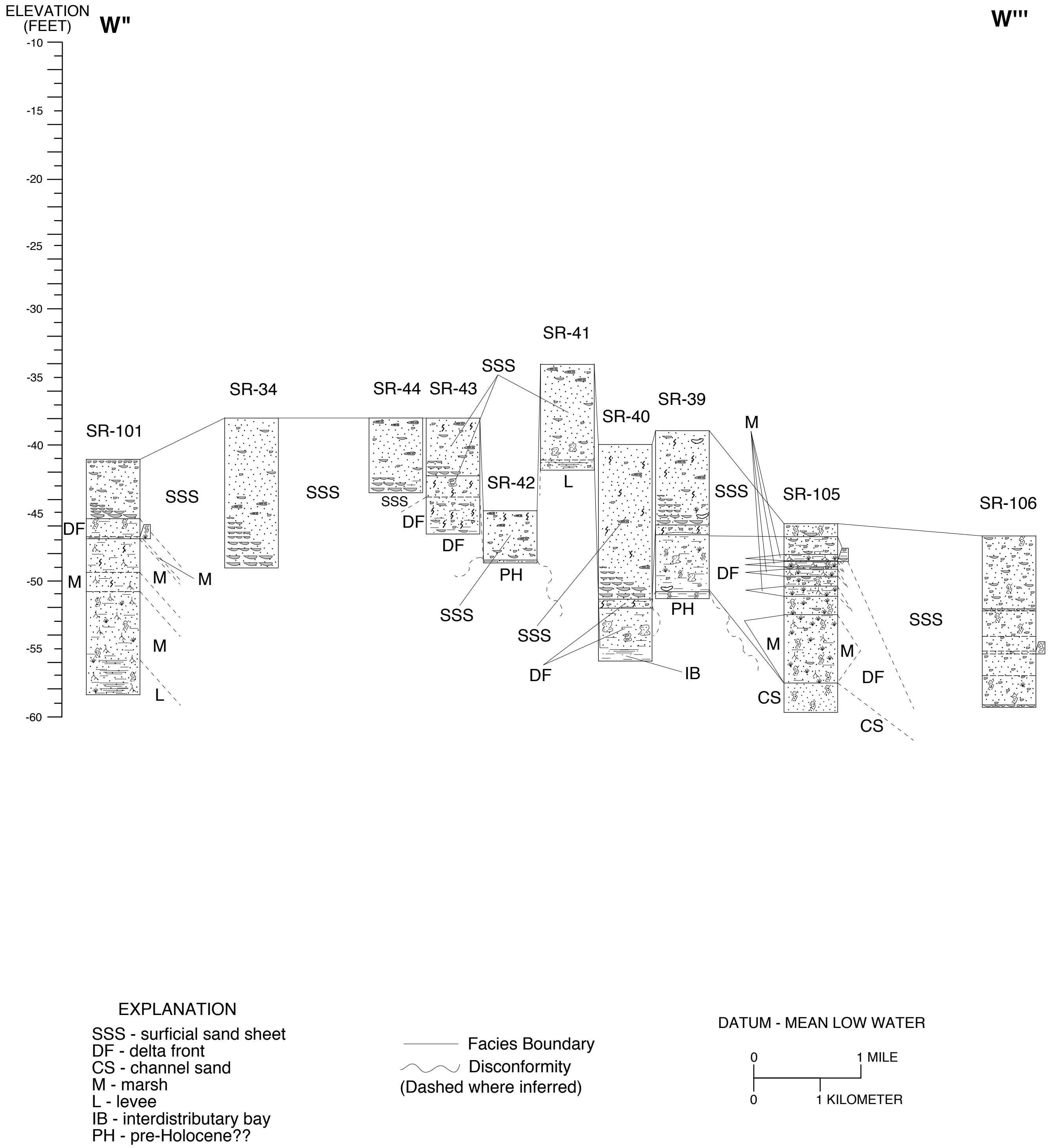


Figure 24.--Cross section W"-W''', along the nearshore Gulf of Mexico.

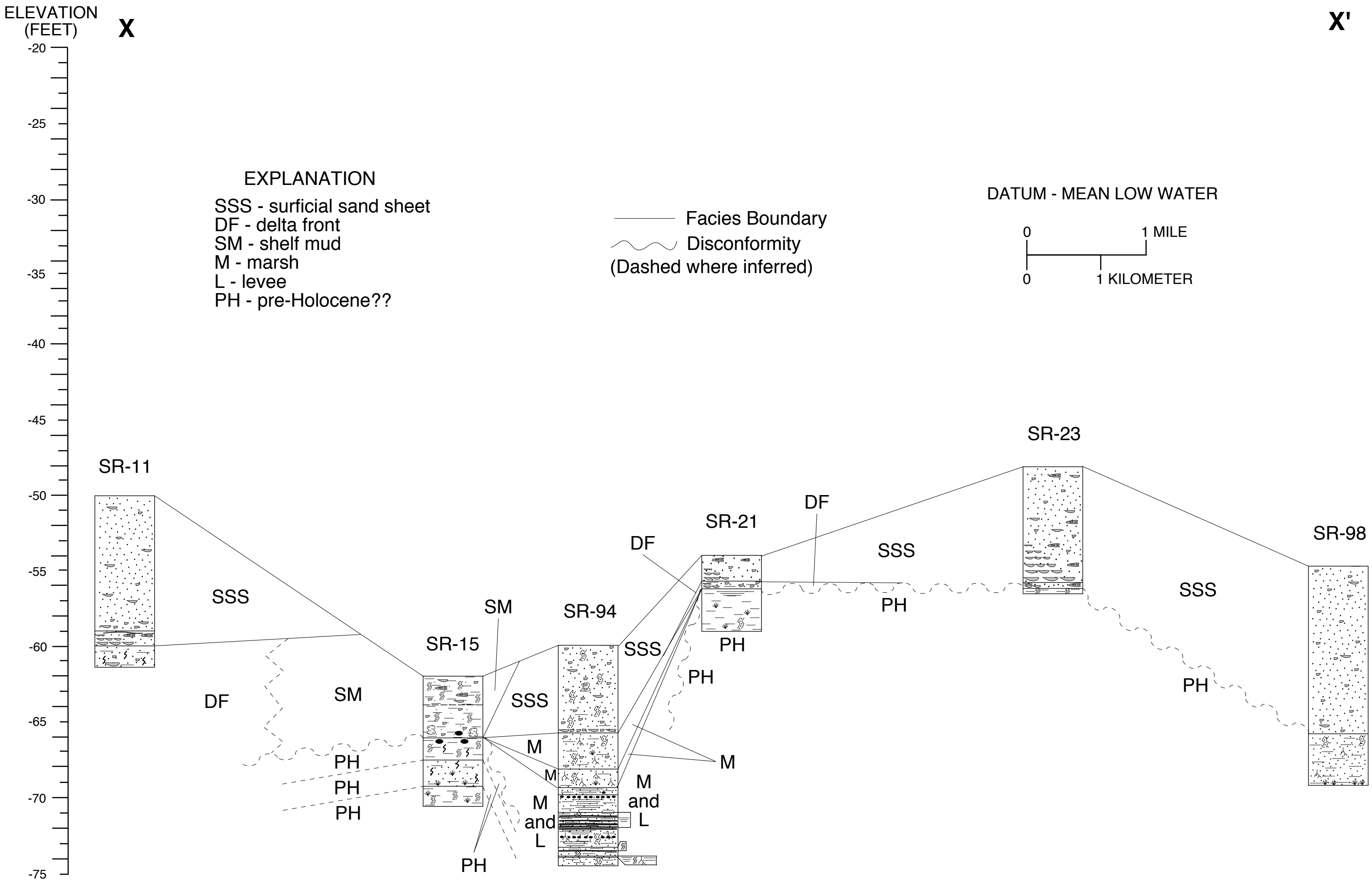


Figure 25.--Cross section X-X', along the nearshore Gulf of Mexico.

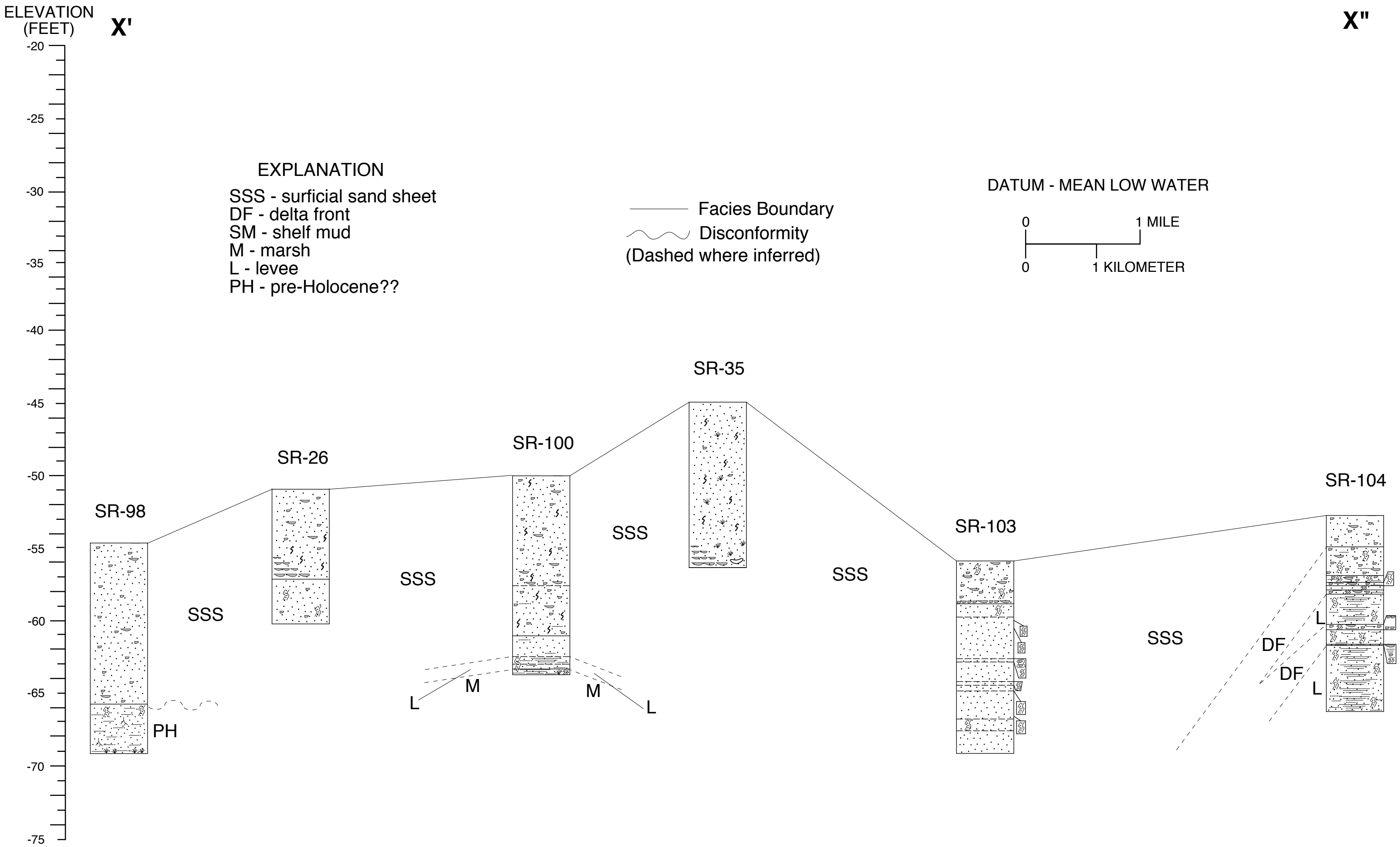


Figure 26.--Cross section X'-X", along the nearshore Gulf of Mexico.

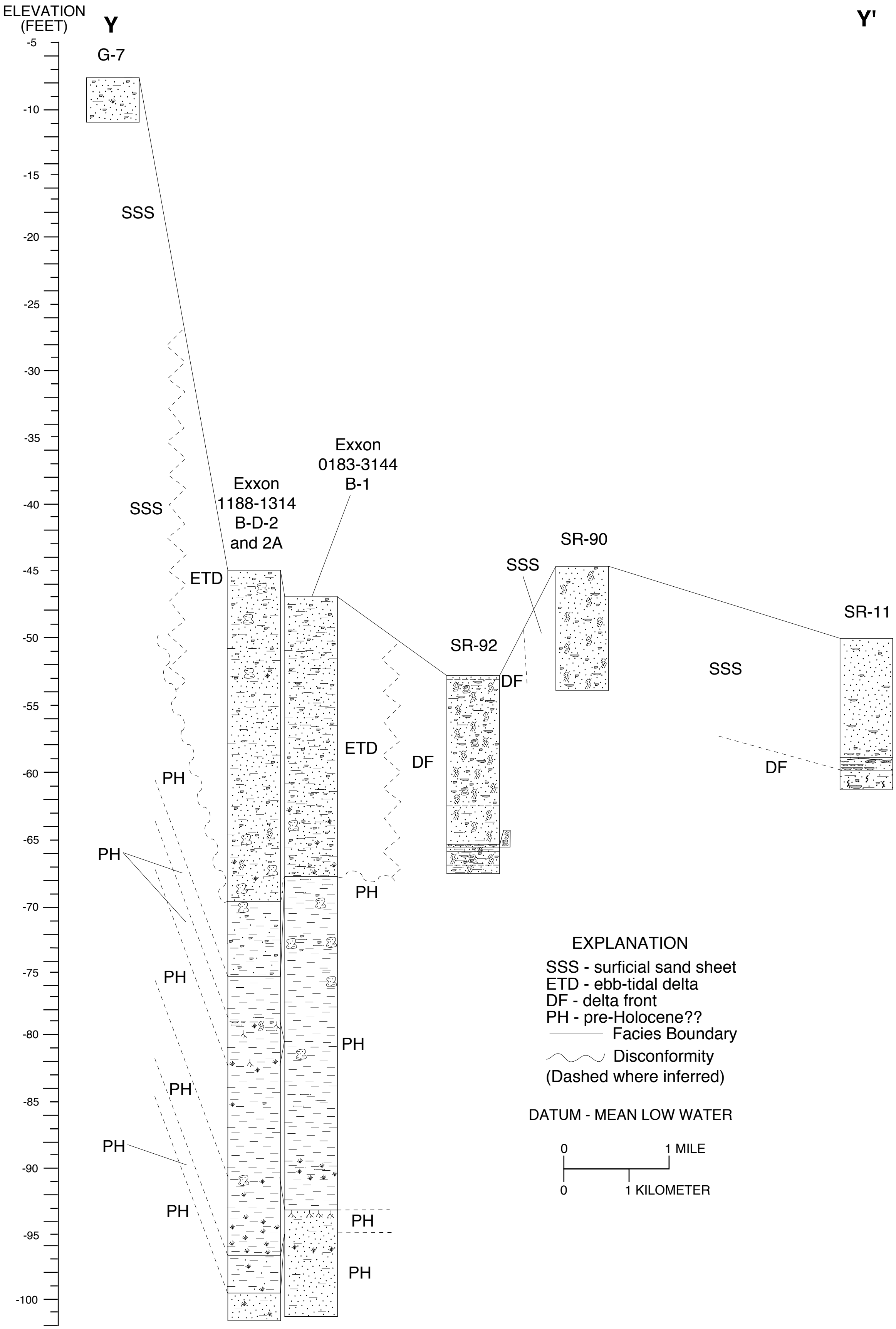


Figure 27.--Cross section Y-Y', along the western margin of the study area.

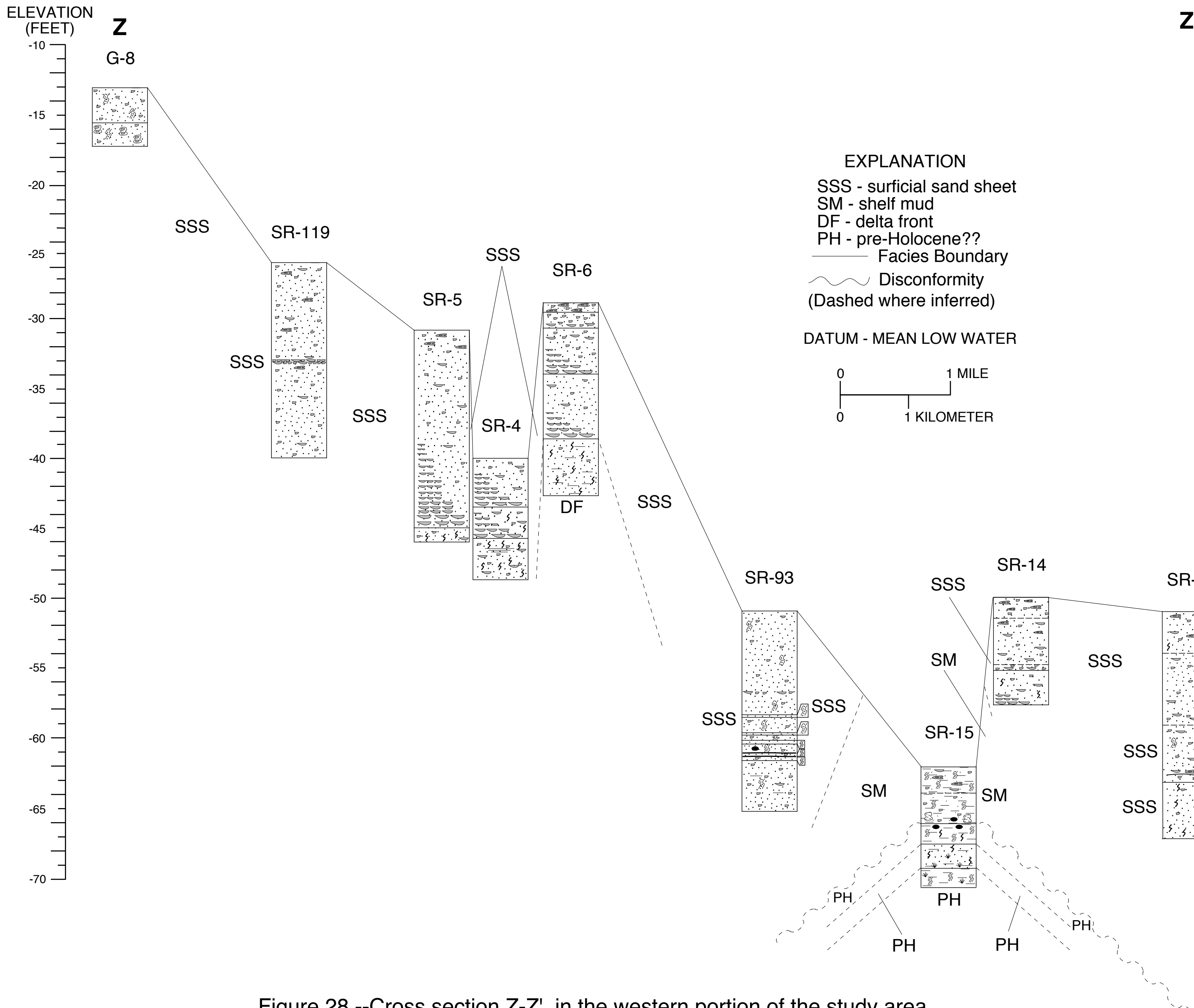
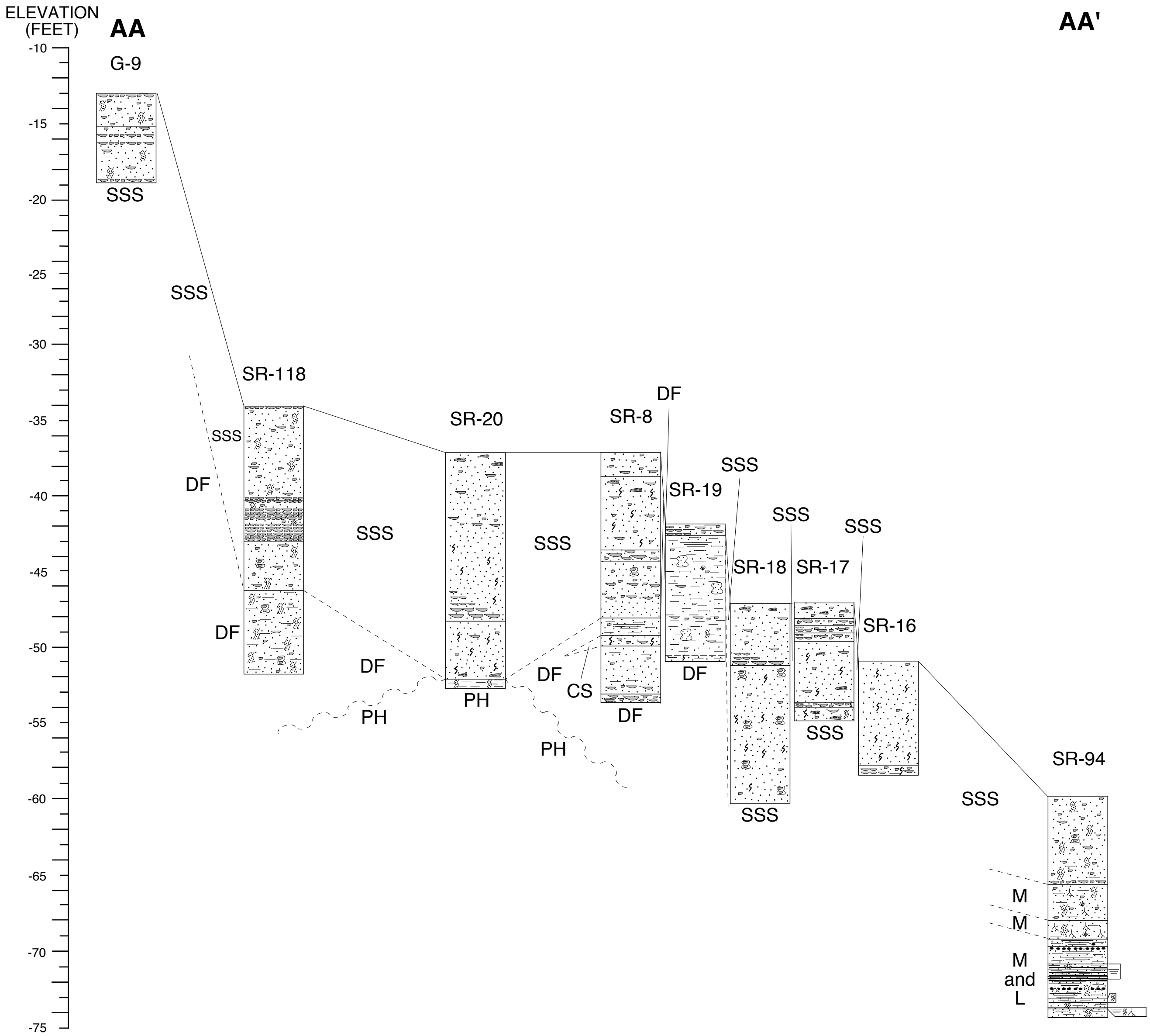


Figure 28.--Cross section Z-Z', in the western portion of the study area.



EXPLANATION

SSS - surficial sand sheet
DF - delta front
CS - channel sand
M - marsh
L - levee
PH - pre-Holocene??

Facies Boundary
Disconformity
(Dashed where inferred)

DATUM - MEAN LOW WATER

0 1 MILE
0 1 KILOMETER

Figure 29.--Cross section AA-AA', in the western portion of the study area.

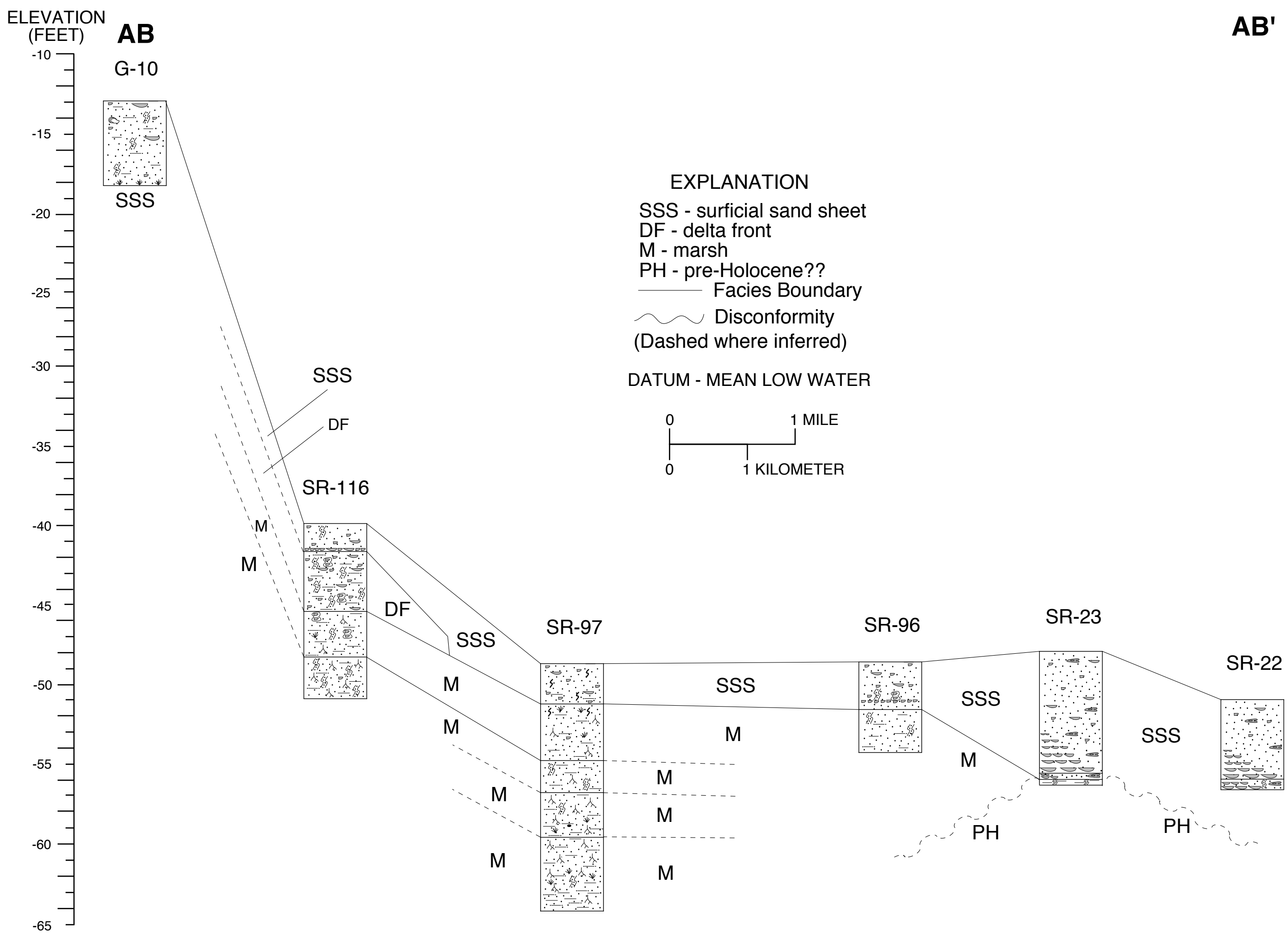


Figure 30.--Cross section AB-AB', in the central portion of the study area.

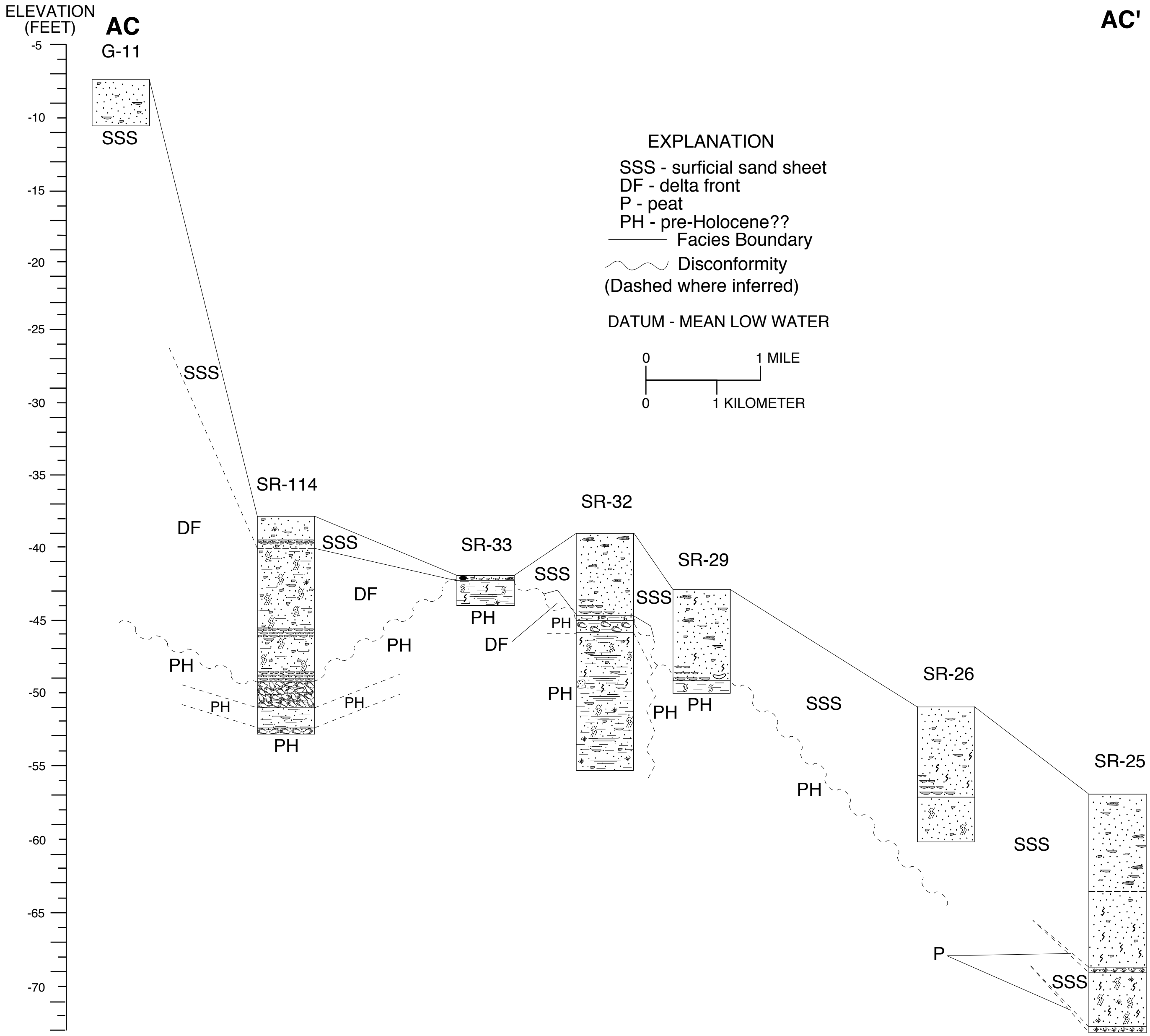


Figure 31.--Cross section AC-AC', in the central portion of the study area.

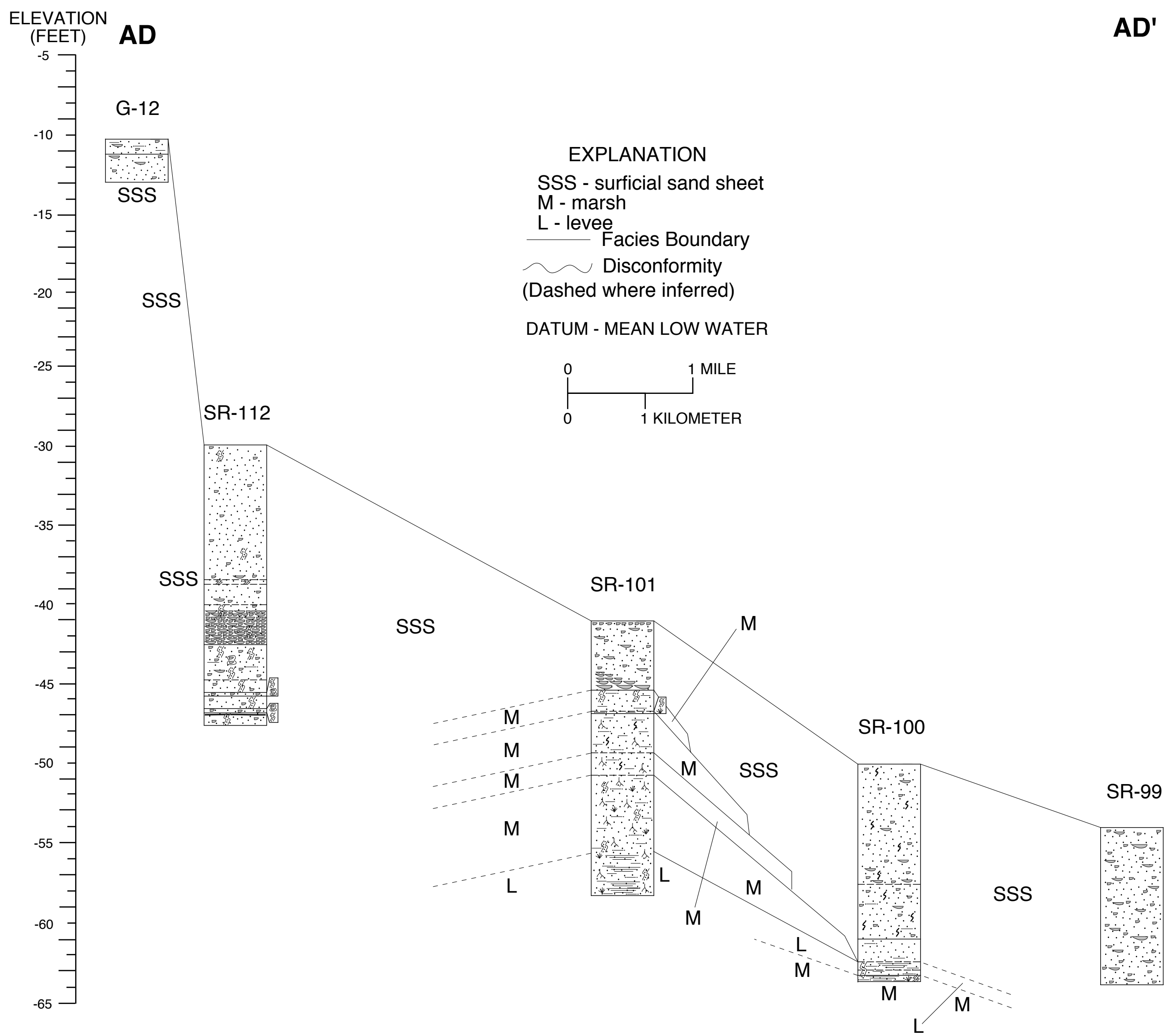


Figure 32 .--Cross section AD-AD', in the central portion of the study area.

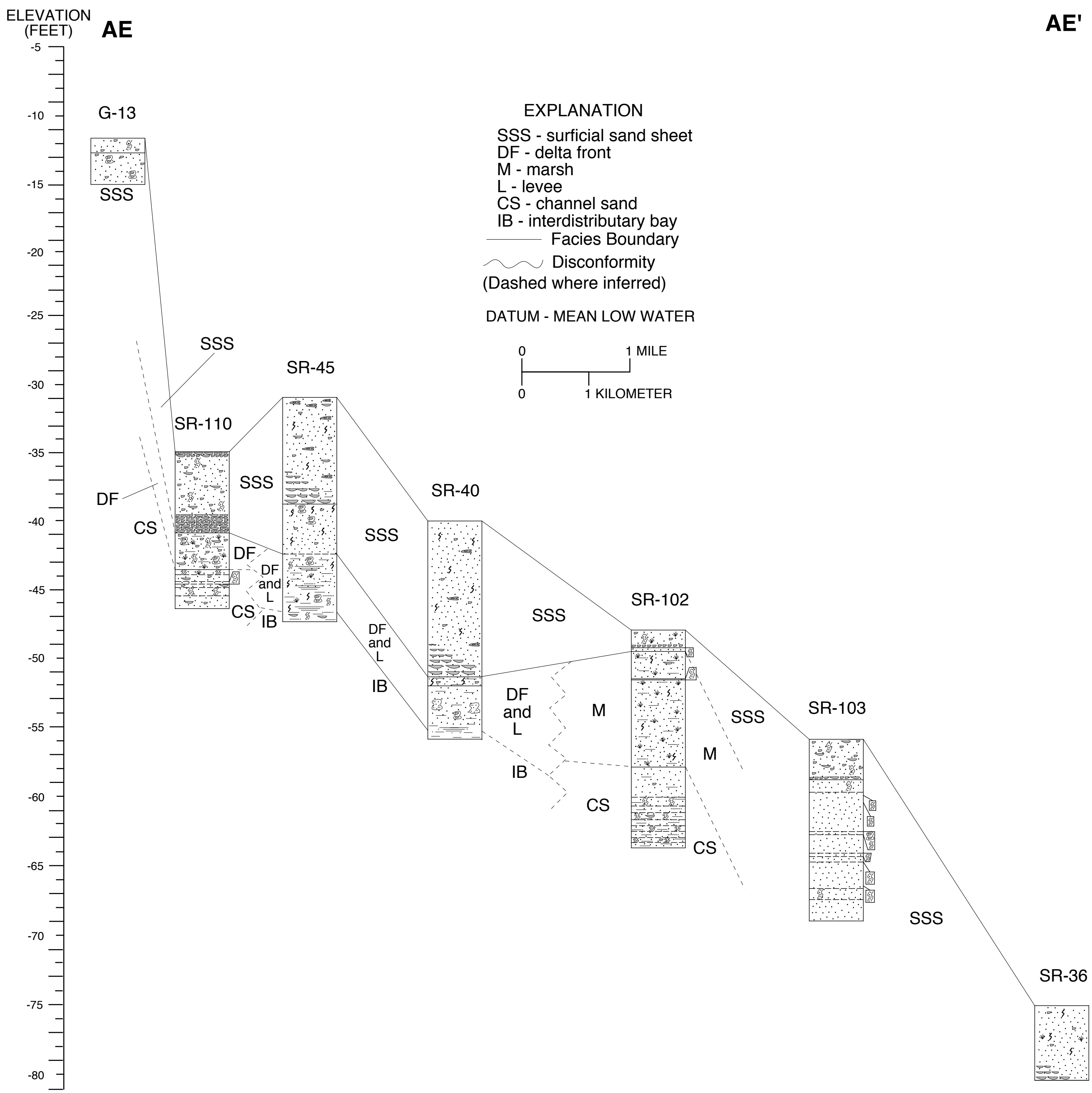


Figure 33.--Cross section AE-AE', in the eastern portion of the study area.

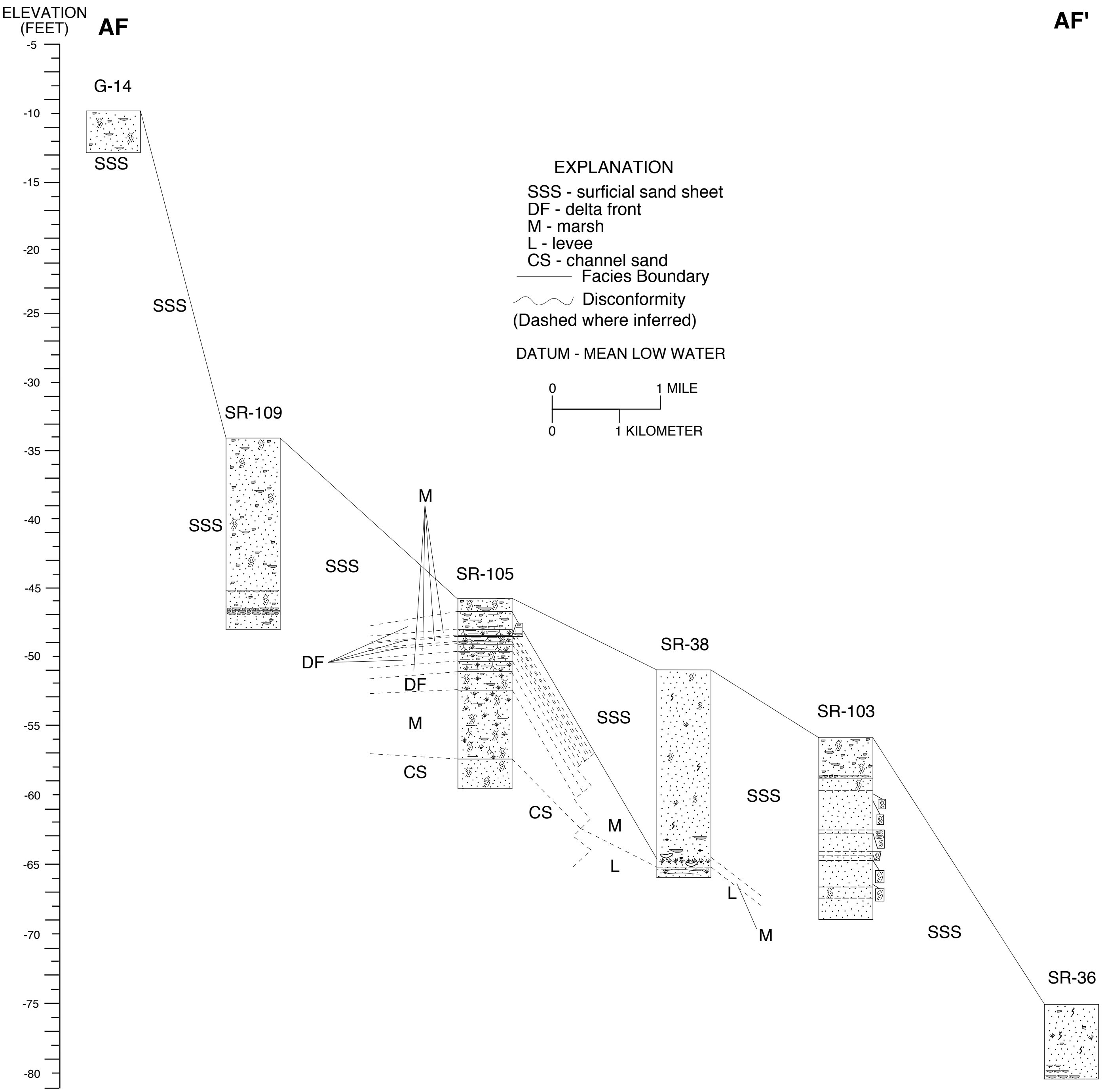


Figure 34.--Cross section AF-AF', in the eastern portion of the study area.

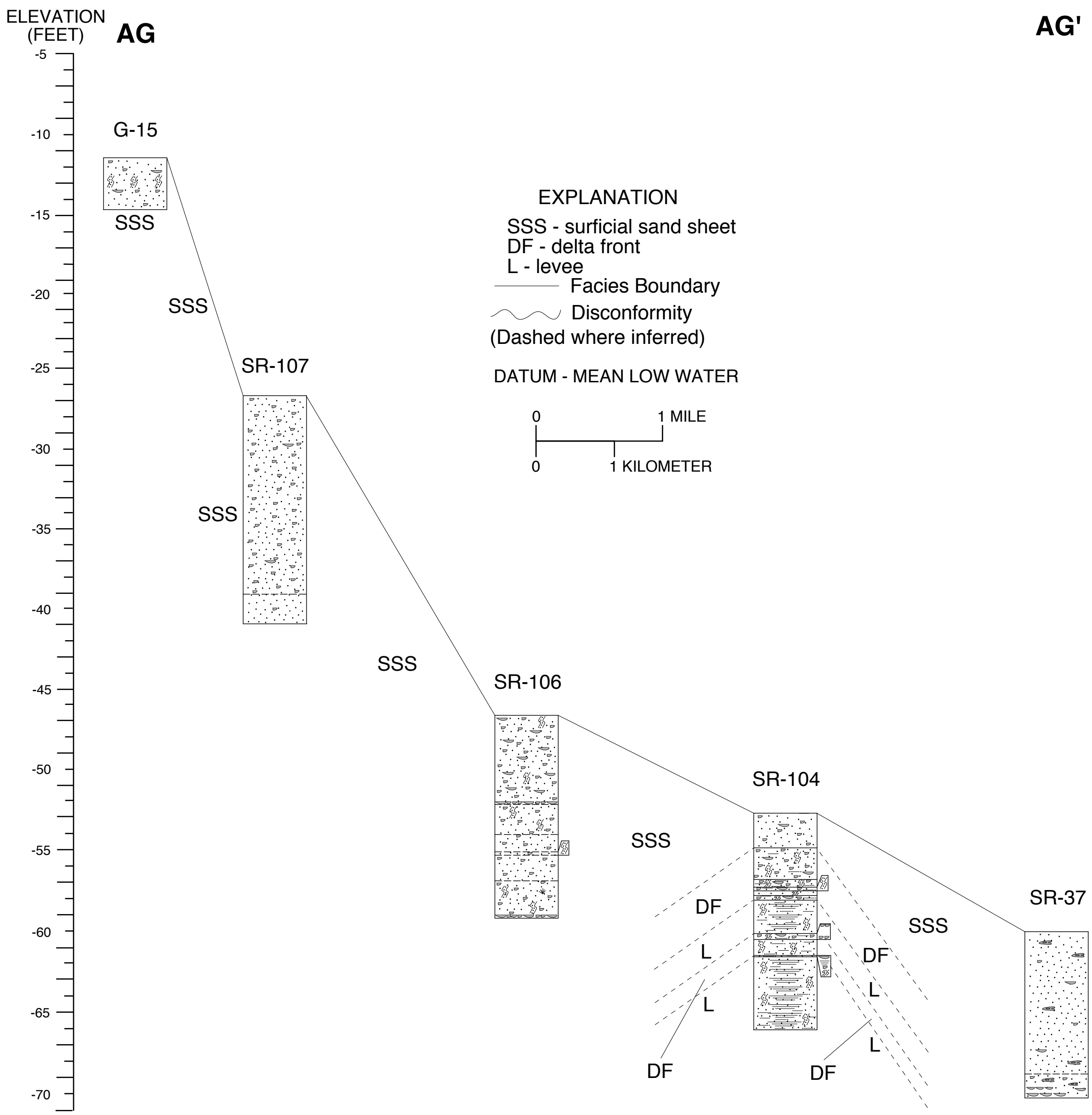


Figure 35.--Cross section AG-AG', along the eastern margin of the study area.

deltaic systems paleochannels. In general, Holocene sediments thicken from east to west toward the ebb-tidal delta of Mobile Bay and within the paleochannels.

Unlike the top of the pre-Holocene sampled by vibracores in Mobile Bay (Hummell and Parker, 1995b) and Mississippi Sound (Hummell and Parker, 1995a), a noticeable lack of paleosol development, rooted zones, marsh deposits, peat, and wood is seen in association with the top of the pre-Holocene within the west Alabama inner continental shelf (Hummell, 1996) and in the present study (where sampled by vibracores, drill holes, and borings). It is probable that marsh and terrestrial vegetation would colonize newly exposed continental shelf produced by the last Pleistocene regression of the sea and subsequent lowstand. Perhaps fluvial-deltaic sedimentation and erosion on the shelf during this time did not allow extensive areas of vegetation cover to develop, or subsequent Holocene transgression of the sea could have destroyed or obscured much of the evidence for vegetation.

STRIKE DIRECTION LITHOFACIES DISTRIBUTION

Cross section V-V"' extends along the northern margin of the study area (figs. 18, 19, 20, 21). Pre-Holocene marsh and estuarine lithofacies underlie the Holocene sediment package. In general, Holocene sediments thicken within paleochannels and thin over paleochannel margins. The western half of the cross section shows a portion of the Mobile-Tensaw fluvial-deltaic system main paleochannel, and ebb-tidal delta and SSS lithofacies that fill it (figs. 19, 20). The ebb-tidal delta lithofacies interfingers with delta front and SSS lithofacies.

Cross section V-V"' shows the preserved sedimentary record of the Holocene Mobile-Tensaw and Perdido fluvial-deltaic systems that once occupied the study area. These sediments consist of marsh and channel sand lithofacies which are found in and along the margins of paleochannels. Overlying delta front lithofacies sediments partially infill the paleochannels and blanket the region.

The SSS lithofacies sands cover the study area, extending from the eastern margin of the ebb-tidal delta of Mobile Bay to the eastern boundary of the study area (figs. 19, 20, 21). These sediments completely buried the Holocene fluvial-deltaic deposits. Cross section V-V"' cuts through transverse bars that are part of the SSS lithofacies (note transverse bar crests located at vibracores SR-119, SR-112, and SR-107 on figs. 19, 20, 21).

Cross section W-W"' (figs. 18, 22, 23, 24) stretches about east-west across the middle of the study area and displays several noteworthy features. In general, cross section W-W"' portrays the same stratigraphic setting shown in cross section V-V"' (figs. 19, 20, 21) - Holocene fluvial-deltaic deposits filling paleochannels and subsequently covered by SSS lithofacies sediments. Holocene lithofacies that fill the Mobile-Tensaw fluvial-deltaic system paleochannel in the western half of the cross section (figs. 22, 23) have thinned from what was seen in cross section V-V"' (figs. 19, 20). In addition, Holocene lithofacies form a thin cover over a divide between two paleochannels (fig. 23, vibracores SR-97 through SR-101); a place to avoid in a sand recovery operation. Note the well-developed marsh lithofacies deposits along the paleochannel margins, east and west of the paleochannel divide (figs. 23, 24). Another channel divide is seen at the eastern endpoint of cross section W-W"' (fig. 24). Holocene sediment is thicker here than over the paleochannel divide shown in figure 21. The SSS lithofacies varies in thickness along the W-W"' cross section line, and with the exception of vibracore SR-27 (fig. 23), extends from the western to eastern boundaries of the study area (figs. 22, 23, 24).

Cross section X-X" (figs. 18, 25, 26) shows a broad paleochannel divide extending from vibracore SR-15 to SR-100 (figs. 25, 26) and perhaps farther eastward. Again, paleochannel margins on each side of the divide show preserved marsh and levee lithofacies deposits. Another paleochannel margin is located near the eastern endpoint of the cross section (fig. 26, vibracore SR-104). The eastern margin of the Mobile-Tensaw fluvial-deltaic system main paleochannel can be seen at the western endpoint of cross section X-X" (fig. 25). A lens of shelf mud lithofacies occurs at vibracore SR-15 (fig. 25) that interfingers with delta front lithofacies sediments to the west and SSS lithofacies sand to the east. Except for the lens of the shelf mud lithofacies, the SSS lithofacies sands extend unbroken across the study area along the cross section line (figs. 25, 26) and thicken from west to east.

To summarize, cross sections V-V"' (figs. 19, 20, 21), W-W"' (figs. 22, 23, 24), and X-X" (figs. 25, 26), show paleochannels of the Mobile-Tensaw and Perdido fluvial-deltaic systems incised in to the late Pleistocene-early Holocene disconformity. Pre-Holocene sediments directly underlying the disconformity are dominantly estuarine lithofacies. Overlying the pre-Holocene are Holocene fluvial-deltaic deposits that have partially infilled the paleochannels. A blanket of SSS lithofacies sand and shelly sand finished infilling the paleochannels and buried the Holocene fluvial-deltaic deposits. The SSS lithofacies sediments cover over 90 percent of the seafloor in the study area and contain interbedded shelf sand ridges and transverse bars. The SSS and Holocene fluvial-deltaic lithofacies interfinger with the ebb-tidal delta lithofacies in the western quarter of the study area. The SSS lithofacies tends to thin over divides between paleochannels, and thickens in paleochannels and where transverse bars are encountered.

DIP DIRECTION LITHOFACIES DISTRIBUTION

The next nine cross sections are oriented about north-south across the study area (fig. 18). Each cross section will be discussed in order from west to east (fig. 18).

Cross section Y-Y' (fig. 27) extends along the western margin of the study area (fig. 18), crossing the eastern margin of the ebb-tidal delta of Mobile Bay and Mobile-Tensaw fluvial-deltaic system main paleochannel. Immediately below the late Pleistocene-early Holocene disconformity, pre-Holocene sediments are interpreted as open bay lithofacies (fig. 27). The Holocene sediment package is comprised of shore proximal SSS lithofacies which interfingers with ebb-tidal delta lithofacies offshore (fig. 27). The ebb-tidal delta lithofacies, in turn, interfingers with delta front lithofacies farther offshore. The western margin of the SSS lithofacies deposit covers a portion of the delta front lithofacies deposit (fig. 27).

Farther east, cross section Z-Z' (figs. 18, 28) shows estuarine pre-Holocene sediments overlain by the lens of shelf mud lithofacies at vibracore SR-15. The SSS lithofacies covers the seafloor along the cross section line except for the presence of some delta front lithofacies (fig. 28).

Cross section AA-AA" (figs. 18, 29) cuts through paleochannels that contain Holocene delta front, channel sand, marsh, and levee lithofacies. All in turn are overlain by a sediment blanket of SSS lithofacies.

Towards the center of the study area (fig. 18), cross section AB-AB' (fig. 30) follows the margin of a paleochannel exposing a thick deposit of Holocene marsh lithofacies. The deposit contains up to four marsh cycles, that, as mentioned before, can be attributed to distributary migration, flooding events, or rising sea level. Some of the delta front lithofacies overlies marsh lithofacies at the northern portion of the cross section (fig. 30). A thin blanket of the SSS lithofacies covers the pre-Holocene and Holocene fluvial-deltaic deposits along the cross section line.

Cross section AC-AC' (fig. 31) is near the center of the study area (fig. 18). Pre-Holocene estuarine sediment, which form a paleochannel divide, underlie delta front and SSS lithofacies deposits. Two peat lithofacies beds occur in vibracore SR-25 at the southern endpoint of the cross section (fig. 31). The SSS lithofacies blankets the seafloor along the cross section line, and thins over the top of the paleochannel divide (fig. 31).

Cross section AD-AD' (figs. 18, 32) is similar to cross section AB-AB' (fig. 30) in that it shows a SSS lithofacies deposit covering a stack of marsh and levee lithofacies beds; the latter representing channel margin deposits.

In the eastern portion of the study area, cross section AE-AE' (figs. 18, 33) shows a Holocene paleochannel-fill deposit comprised of channel sand, delta front, levee, marsh, and interdistributary bay lithofacies. Fine-scale vertical and lateral change in lithofacies is interpreted as indicating a shallow, rapidly changing delta (fig. 33). The SSS lithofacies shelly sands tend to thicken in paleochannels in the northern and southern portions of the cross section and thin over the paleochannel margin at vibracore SR-102 (fig. 33).

Farther east, cross section AF-AF' (figs. 18, 34) illustrates even finer scaled lithofacies change at a channel margin than is seen on cross section AE-AE' (figs. 18, 33). Such fine-scale change is interpreted as progradation of delta front lithofacies during river flood events. The SSS lithofacies thins over the paleochannel margin (fig. 34).

At the eastern margin of the study area, cross section AG-AG' (figs. 18, 35) cuts through a paleochannel margin comprised of interbedded Holocene-age delta front and levee lithofacies sediments. The SSS lithofacies covers the seafloor along the cross section line, thinning over the paleochannel margin (fig. 35).

Cross sections indicate that sea-level rise and paleotopography controlled Holocene sedimentation. By mapping the pre-Holocene and Holocene sediments it is concluded that: (1) pre-Holocene deposits were incised by ancestral Perdido and Mobile-Tensaw fluvial-deltaic systems during late Pleistocene lowstand, (2) as sea level rose the paleochannels were partly backfilled with Holocene fluvial-deltaic sediments, (3) reworking of shelf sediments and formation of a longshore transport system in the present day nearshore Gulf of Mexico during late Holocene transgression, produced a massive SSS lithofacies sand sheet with imbedded shelf sand ridges and transverse bars, (4) the SSS lithofacies completed infilling of paleochannels and buried Holocene deltaic deposits, (5) the ebb-tidal delta of Mobile Bay formed by vertical accretion and progradation during late Holocene transgression of the sea, and received coarse- and fine-grained sediments from the Mobile-Tensaw fluvial-deltaic system and by longshore drift (Hummell, 1996), (6) Holocene ebb-tidal delta of Mobile Bay sediment interfingers with Holocene fluvial-deltaic and SSS lithofacies sediment in the western quarter of the study area, (7) on the present-day east Alabama inner continental shelf, the Holocene section is thickest in paleochannels and thinnest over divides between paleochannels, and (8) pre-Holocene sediment penetrated by vibracores and borings are interpreted as mostly estuarine lithofacies of probable Pleistocene age.

INCISED PALEOCHANNELS

Kindinger and others (1991, 1994), Hummell (1996), McBride (1997) and Parker and others (1997) discussed the seismic stratigraphy of the Alabama inner continental shelf. Sediment can be divided into two major sequences that are separated by a type 1 unconformity (disconformity) (Van Wagoner and others, 1988), the major late Pleistocene-early Holocene lowstand erosional surface (Brande, 1983; Kindinger, 1988; Reed, 1988; Kindinger and others, 1989, Hummell and Parker, 1995a, b; Hummell, 1996; McBride and others, 1997; Parker and others, 1997). This transgressive surface is readily recognized on shallow seismic lines as well as in vibracores, borings, and drill holes, underlying all of Mobile Bay, Mississippi Sound, and the Alabama inner continental shelf. On shallow seismic records, the reflective transgressive surface represents a significant change in lithology and density (velocity) between the unconsolidated surficial Holocene sediments and the underlying much more consolidated pre-Holocene deposits (Hummell and Parker, 1995a, b; Hummell, 1996). This surface represents a time-transgressive Holocene marine flooding surface (the time of most recent marine inundation), and as such, early Holocene age nonmarine to fluvial-deltaic sediments may exist below the surface in some updip areas.

The late Pleistocene-early Holocene disconformity in coastal Alabama has been mapped by Otvos (1976), Hummell and Parker (1995a, b), Hummell (1996), and Parker and others (1997). The disconformity is characterized by significant relief due to stream erosion associated with sea level fall. Evidence of subaerial exposure along this eroded surface is seen in sediments from vibracores and borings which penetrated the disconformity. Channel-fill deposits associated with late eustatic sea level fall or early rise are classified as the updip part of a lowstand wedge (Van Wagoner and others, 1988). These deposits are apparent within the stream channels along the disconformity seen on the seismic records from Mobile Bay and Mississippi Sound (Hummell and Parker, 1995a, b). Overlying these sediments are Holocene transgressive deposits.

In the study area, the late Pleistocene-early Holocene disconformity was formed by erosion of pre-Holocene deposits of the Mobile-Tensaw and Perdido River alluvial valleys during late Pleistocene regression and sea-level lowstand and during early Holocene. Concurrent with sea-level fall, a network of channels was incised into the pre-Holocene deposits. Using information from Kindinger and others (1994), Hummell and Parker (1995b), and vibracore and boring data from this study, the network of incised channels was mapped for the study area (fig. 36). The pair of paleochannels in the western side of the study area belongs to the Mobile-Tensaw fluvial-deltaic system, and the eastern pair of paleochannels is from the Perdido fluvial-deltaic system (fig. 36). The short length of the vibracores in the Gulf of Mexico shoreface causes Perdido paleochannel mapping to be imprecise. It is postulated that the two Perdido paleochannels join just south of Gulf Shores (fig. 36). The Perdido paleochannels are mapped for the first time in the present study.

Paleochannels of the Mobile-Tensaw fluvial-deltaic system have been mapped in Mobile Bay (Hummell and Parker, 1995b) and on the west Alabama inner continental shelf (Kindinger, 1988; Parker, 1990; Kindinger and others, 1991, 1994; Hummell, 1996). Paleochannels of the Escatawpa fluvial-deltaic system in Mississippi Sound were mapped by Hummell and Parker (1995a).

STRATIGRAPHIC MAPS

An attempt was made to map the Late Pleistocene-early Holocene disconformity in the study area using lithologic data from vibracores and borings assembled for this study. This was done for Mobile Bay (Hummell and Parker, 1995b), the Alabama portion of Mississippi Sound (Hummell and Parker, 1995a), and west Alabama inner continental shelf (Hummell, 1996). As was found by Parker and others (1997), the data was too few to accurately map this surface in the east Alabama inner continental shelf. The lithologic data was used however, to produce a series of isopach maps of the Holocene sediments in the east Alabama inner continental shelf.

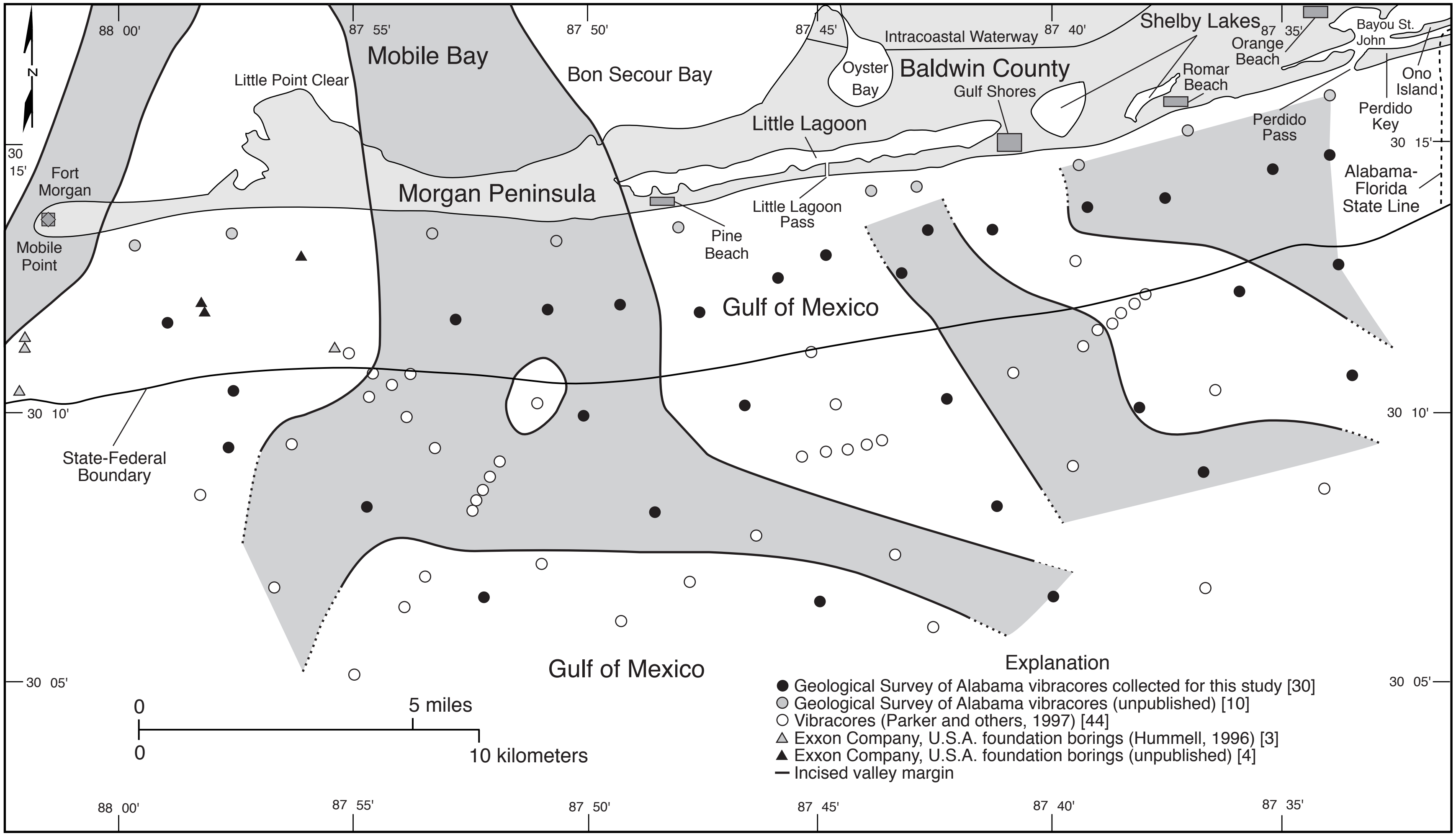


Figure 36.--Late Wisconsinan incised channels (shaded) mapped with core data in the east Alabama inner continental shelf study area (Mobile Bay valleys modified from Hummell and Parker, 1995b).

Figure 37 shows the total thickness of Holocene sediments in the study area measured in borings and vibracores. In some cases, sediments are thicker in paleochannels, but the relationship is more apparent in strike direction (east to west oriented) cross sections. Holocene sediments are thickest in the ebb-tidal delta of Mobile Bay (western quarter of the study area) (fig. 37). The relationship between paleochannels and Holocene sediment thickness is improved somewhat by removal of paleochannel margin deposits (marsh, levee, and peat lithofacies) (figs. 37, 38).

As mentioned previously, the SSS lithofacies is an ideal source of beach nourishment sand for Morgan Peninsula Gulf of Mexico beaches. An isopach map of the SSS lithofacies in the study area appears as figure 39. Variation in sediment thickness is not only associated with underlying paleochannels and paleochannel divides, but also reflects the presence of shelf sand ridges and transverse bars. The short length of some vibracores, especially in the shoreface zone, minimizes SSS lithofacies thickness. Figure 40 shows the SSS lithofacies overlain with the network of paleochannels.

The small volume and geographic extent of delta front lithofacies when compared to SSS lithofacies can be seen in the delta front lithofacies isopach map (fig. 41). Delta front lithofacies depocenters are limited to the margin of the ebb tidal delta of Mobile Bay, the paleochannel divide south of Little Lagoon, and a portion of a Perdido paleochannel (fig. 41). As mentioned previously, the delta front lithofacies, due to its limitations of volume, depth, geographic extent, and mud content, does not present an attractive sand resource target for Morgan Peninsula beach nourishment projects. However, if delta front lithofacies sediments are inadvertently recovered during an SSS lithofacies mining operation, delta front lithofacies sediment does not pose a contamination problem. Figure 42 is an isopach map of delta front and SSS lithofacies in the study area. The network of paleochannels is placed over figure 42 and appears as figure 43.

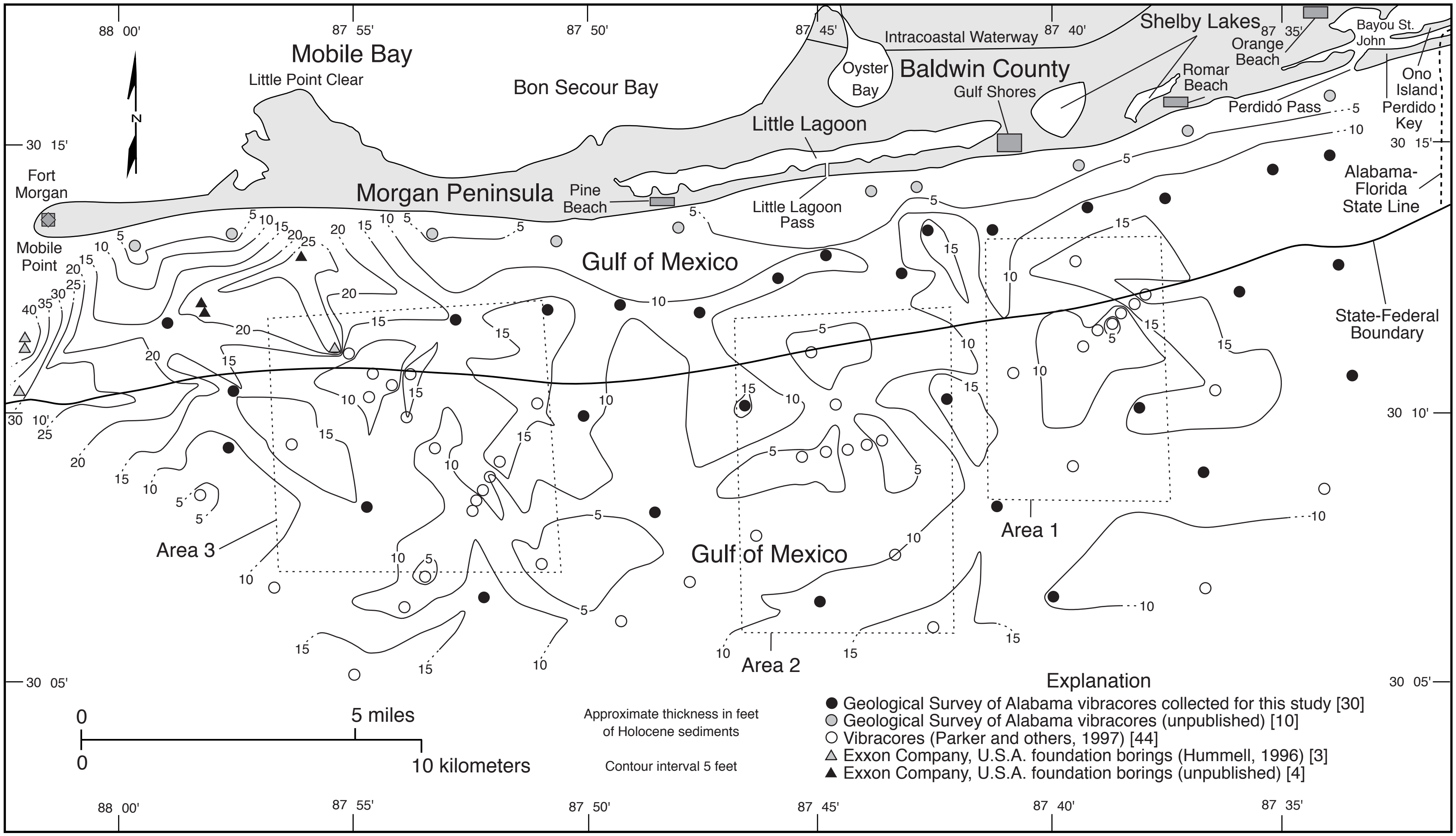


Figure 37.--Isopach map of Holocene sediments in the east Alabama inner continental shelf study area.

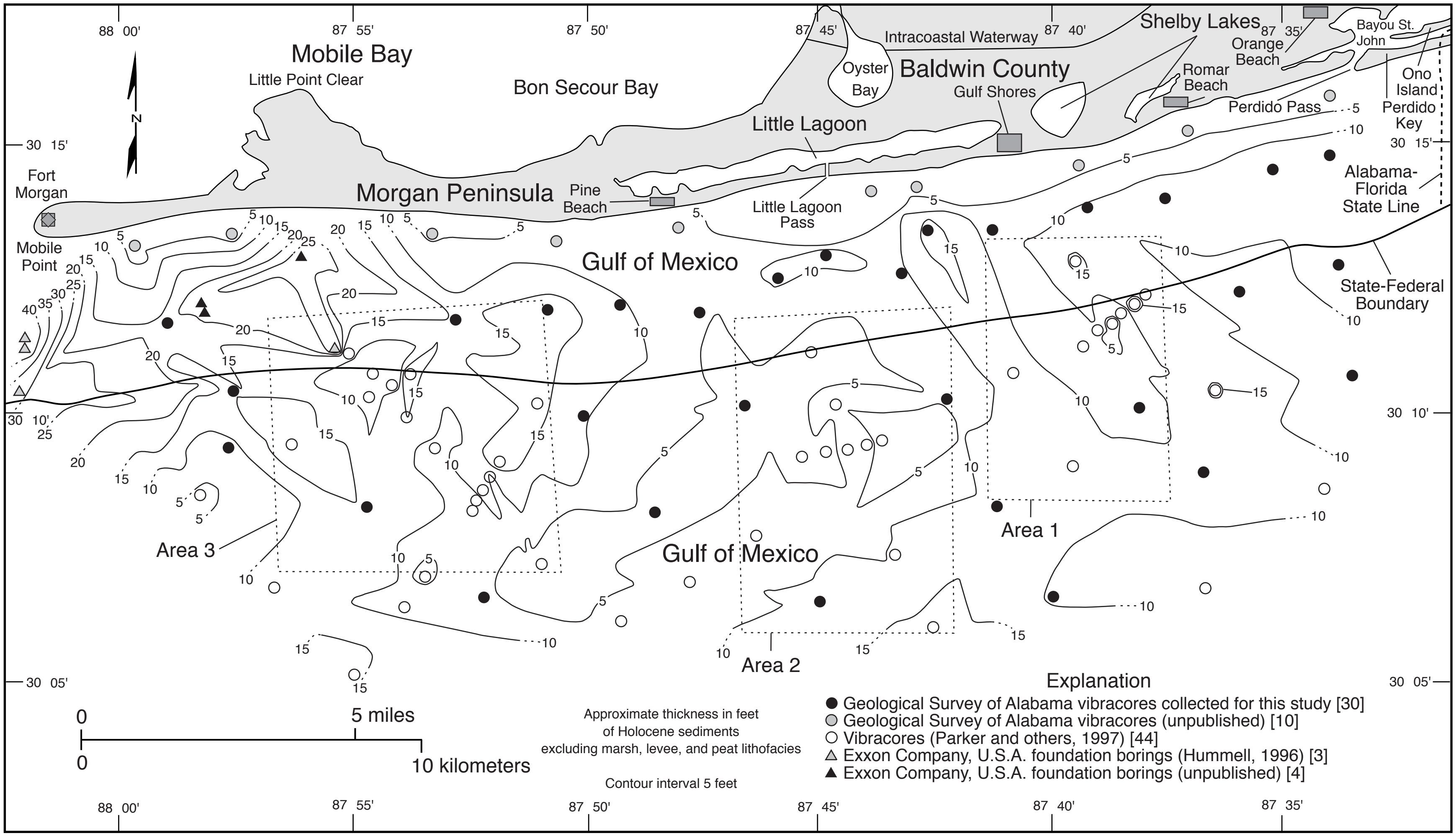


Figure 38.--Isopach map of Holocene sediments excluding marsh, levee, and peat lithofacies in the east Alabama inner continental shelf study area.

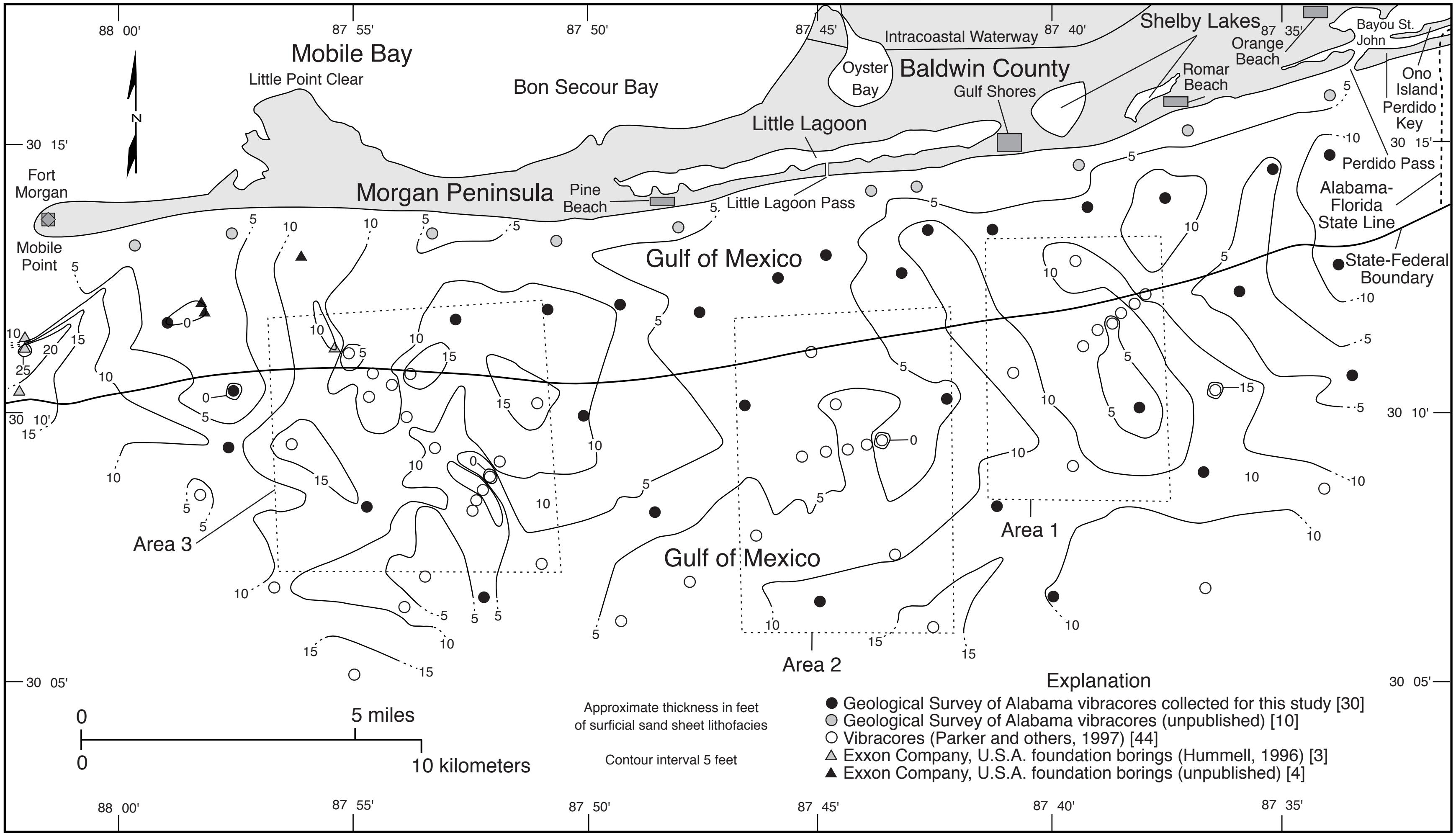


Figure 39.--Isopach map of surficial sand sheet lithofacies in the east Alabama inner continental shelf study area.

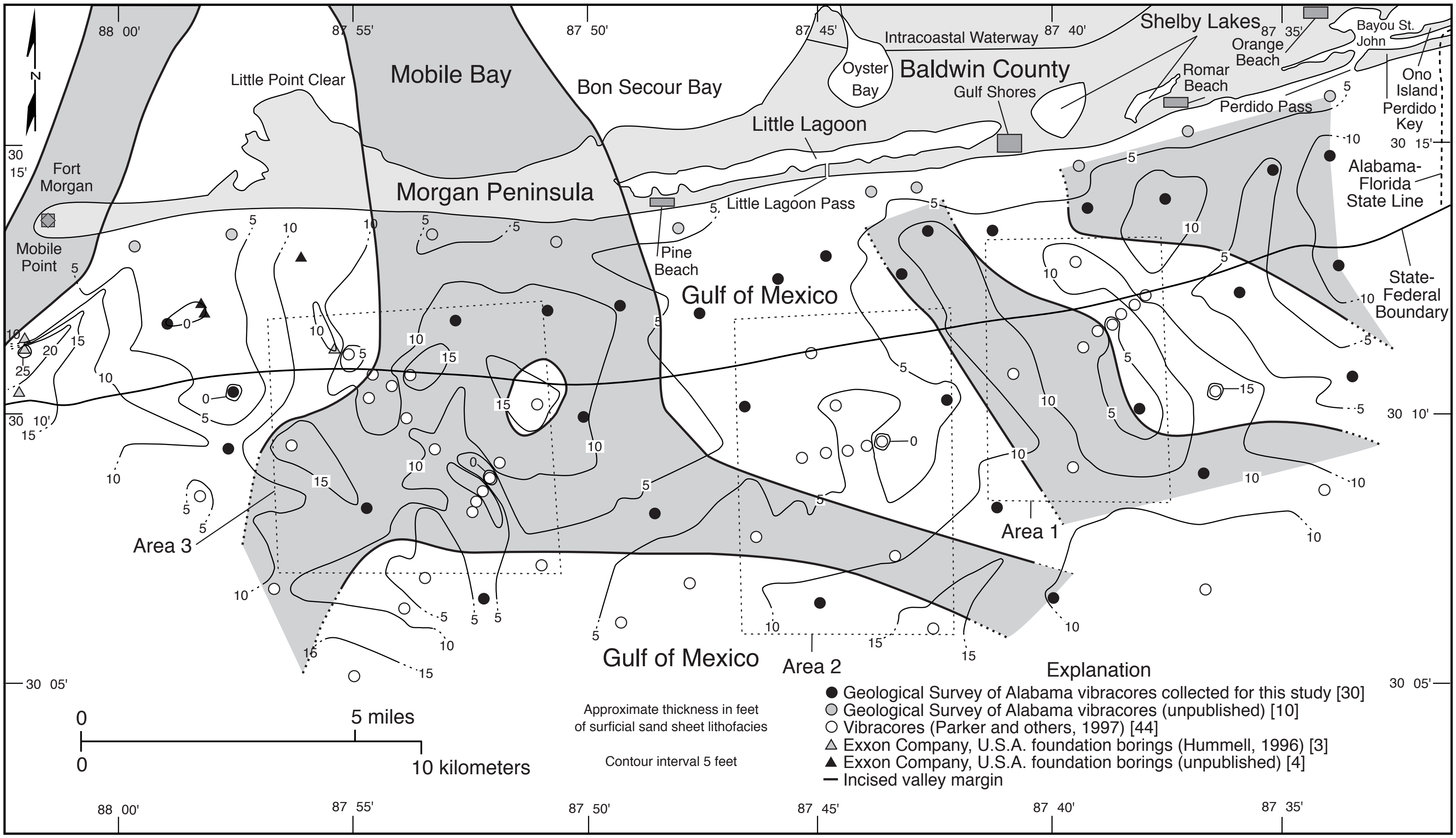


Figure 40.--Isopach map of surficial sand sheet lithofacies and paleochannels (shaded) in the east Alabama inner continental shelf study area.

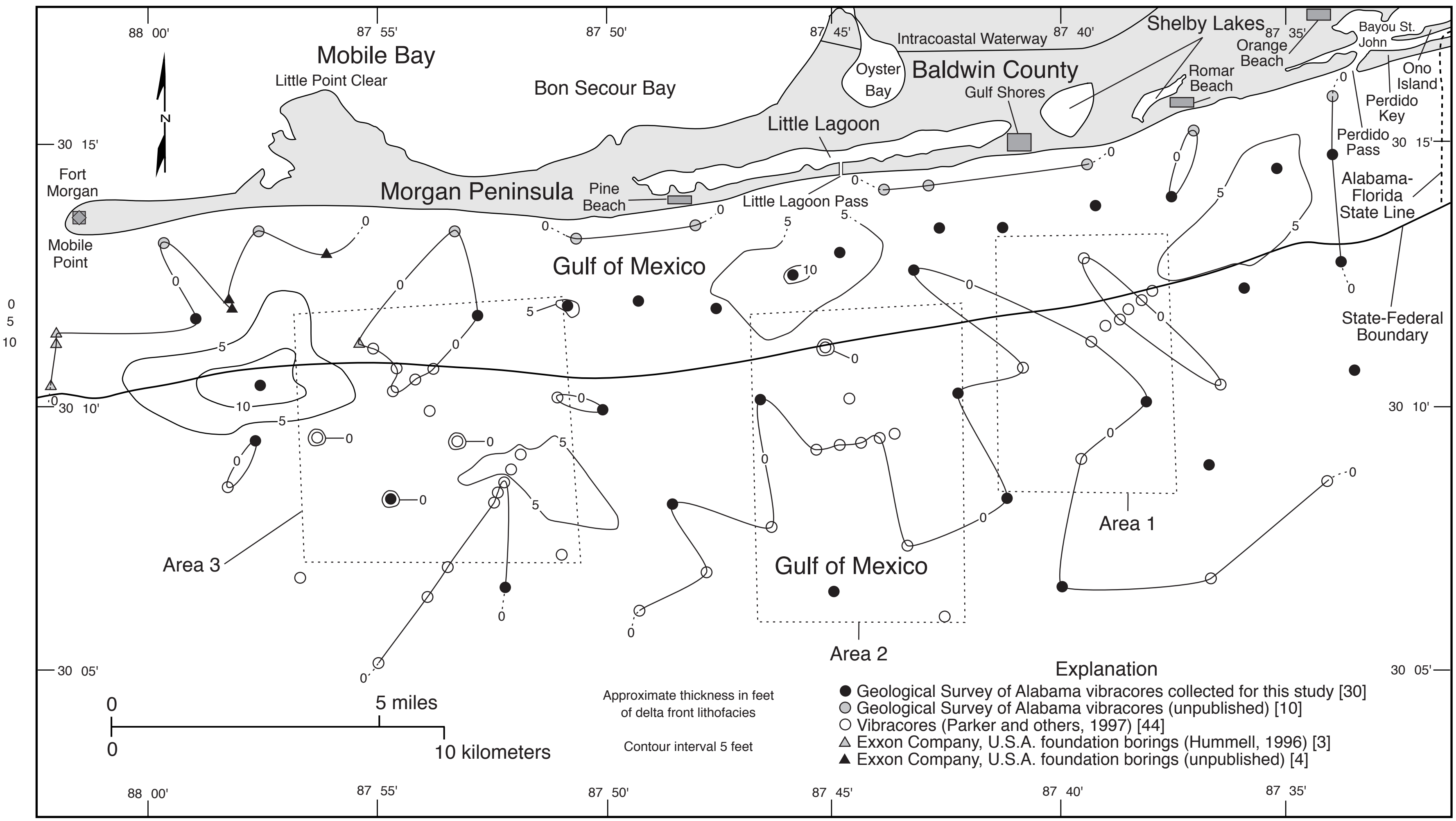


Figure 41.--Isopach map of delta front lithofacies in the east Alabama inner continental shelf study area.

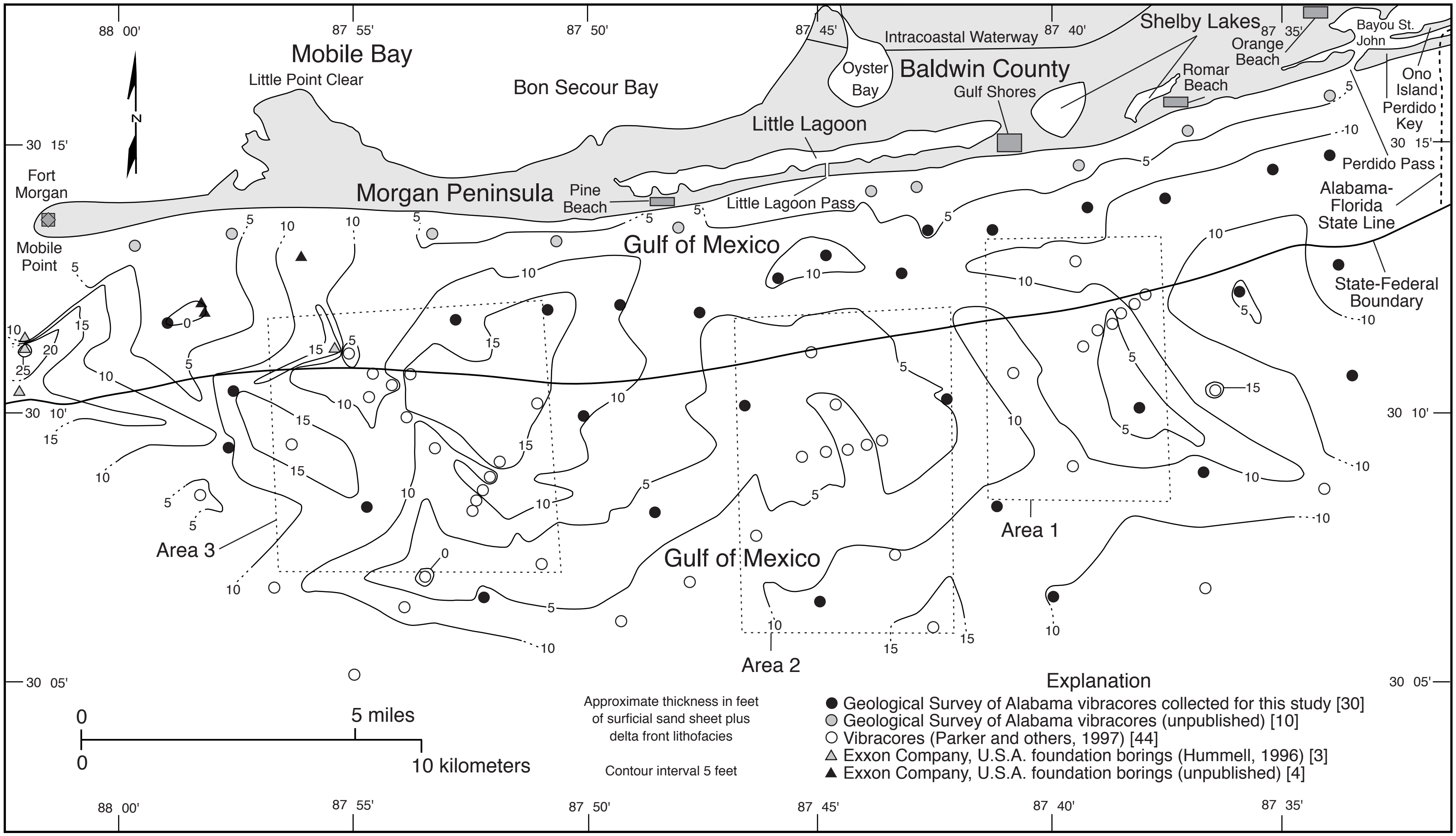


Figure 42.--Isopach map of surficial sand sheet plus delta front lithofacies in the east Alabama inner continental shelf study area.

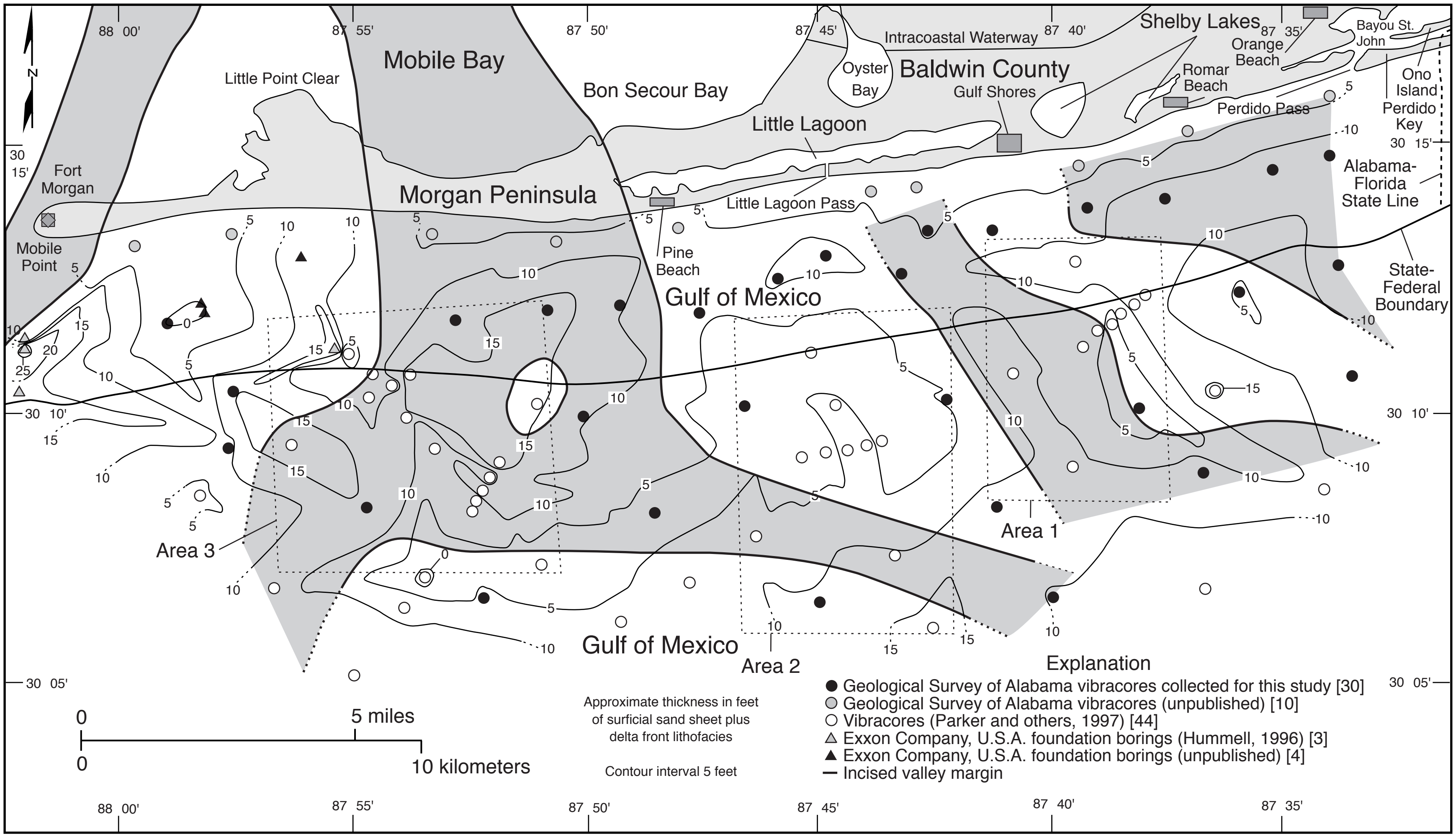


Figure 43.--Isopach map of surficial sand sheet plus delta front lithofacies and paleochannels (shaded) in the east Alabama inner continental shelf study area.

SAND RESOURCE POTENTIAL OF THE SSS LITHOFACIES

Parker and others (1997) evaluated the resource potential of their graded shelly sand lithofacies (included within the SSS lithofacies of Hummell, 1996) and onshore sand resources by comparing the sediment character of these deposits with the native sediment occurring on eroding Gulf of Mexico shoreline. The SSS lithofacies textural data in the present study compares favorably with the characteristics of sediment samples collected from eroding Gulf of Mexico shoreline and analyzed by Parker and others (1997).

Total estimated volume of SSS lithofacies in the study area was calculated from the SSS isopach map (fig. 39). Sand volume calculations were confined to the geographic limits of the vibracore and boring database (fig. 44). The estimated volume of SSS lithofacies appears in table 5.

The volume of sand available from the SSS lithofacies is enormous, far exceeding near- and long-term Gulf of Mexico beach nourishment needs of Morgan Peninsula. With abundant sand resources available, beach nourishment borrow sites are constrained by the economics of the specific beach nourishment project, ship and gas industry infrastructure, historical and archaeological sites, sites of unexploded military ordnance, dredge material disposal sites, areas where the SSS lithofacies deposit is too thin, environmental concerns, and areas where the borrow site would not alter the wave climate and thereby cause or aggravate shoreline erosion and compromise shoreline storm protection.

HURRICANE DANNY MUD LAYER IN SAND RESOURCE AREA 4

Hurricane Danny, a category 1 hurricane (Saffir/Simpson Hurricane Scale - table 6), impacted coastal Alabama July 18-20, 1997. The storm transported mud out of Mobile Bay and onto the inner continental shelf south of Main Pass. The hurricane deposited a mud layer on the shelf

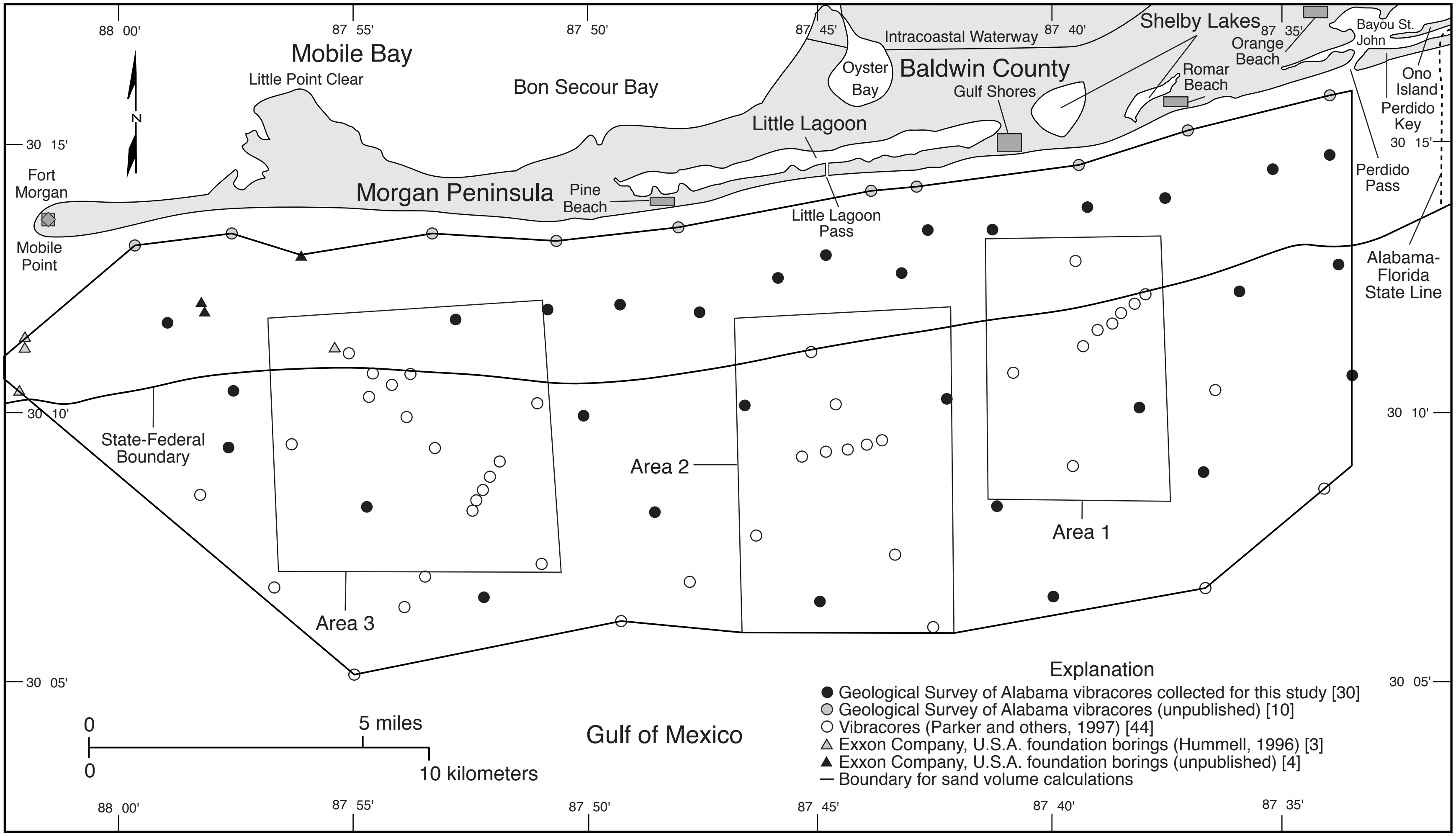


Figure 44.--Map showing locations of vibracores, foundation borings, and area used to estimate the volume of surficial sand sheet lithofacies in the east Alabama inner continental shelf study area.

Table 5.--Estimated volume of surficial sand sheet lithofacies in the east Alabama inner continental shelf study area (see figure 44 for exact area used in volume calculations)

Region	Estimated volume of surficial sand sheet facies (cubic yards)
Sand resource target area 1	
State waters portion	46,108,866
Federal waters portion	129,957,726
Total for area 1	176,066,592
Sand resource target area 2	
State waters portion	9,758,221
Federal waters portion	193,540,439
Total for area 2	203,298,660
Sand resource target area 3	
State waters portion	85,364,553
Federal waters portion	244,223,705
Total for area 3	329,588,258
Total for state waters	564,003,115
Total for federal waters	1,183,691,439
Total for state and federal waters	1,747,694,554

Table 6.--Saffir/Simpson hurricane scale (modified from U.S. Army Corps of Engineers, 1981)

Category	Central Pressure		Winds	Storm Surge	Damage
	in millibars	in inches	in miles per hour	in feet	
1	greater than 980	greater than 28.94	74 - 95	4 - 5	minimal
2	965 - 979	28.50 - 28.91	96 - 110	6 - 8	moderate
3	945 -964	27.91 - 28.47	111 - 130	9 - 12	extensive
4	920 - 944	27.17 - 27.88	131 - 155	13 - 18	extreme
5	less than 920	less than 27.17	greater than 155	greater than 18	catastrophic

which not only filled a portion of the outer Mobile Ship Channel, but partly covered a sand deposit in sand resource area 4 that was mapped by the GSA and MMS (Hummell and Smith, 1995, 1996; Hummell, 1998) as a resource option for Dauphin Island beach nourishment projects (fig. 13). As part of the field work for the present study, the GSA and MMS collected five vibracores in the sand resource body to determine the geographic distribution and thickness of the mud layer.

Figure 45 is a map of sand resource area 4 showing the locations of the sand resource body and five vibracores. The columnar sections for the vibracores are included in appendix A (A-62-66).

Table 7 summarizes the results of the mud layer investigation. Pre-hurricane detailed mapping of the sand resource body by GSA and MMS in 1995 and 1996 (Hummell and Smith, 1995, 1996; Hummell, 1998) was used to estimate the thickness of SSS lithofacies that was present at the five vibracore locations prior to Hurricane Danny. In addition, the SSS lithofacies was exposed at the seafloor at the five core locations prior to the hurricane. The five vibracores showed that the thickness of the SSS lithofacies was reduced by erosion at some vibracore locations or thickness increased at other locations by sediment deposition (table 7). The SSS lithofacies was exposed at the seafloor at four of the five vibracore locations. Only one core location, SR-85 (fig. 45, table 7), showed the presence of the mud layer, the top of which was exposed at the seafloor and measured about 2 ft thick.

Hurricane Georges, a category 1-2 hurricane (Saffir/Simpson Hurricane Scale) (table 6), impacted coastal Alabama September 27, 1998, causing a storm surge of 8-10 ft and 15 in of rain. The storm deposited a layer of SSS lithofacies sand in the same area that Hurricane Danny had deposited a mud layer. The effects of Hurricane Georges on the Alabama inner continental shelf have not been investigated by GSA and MMS as field work for the present study was completed prior to Hurricane Georges and resources are unavailable for the GSA to collect post-hurricane vibracores and seafloor samples at this time.

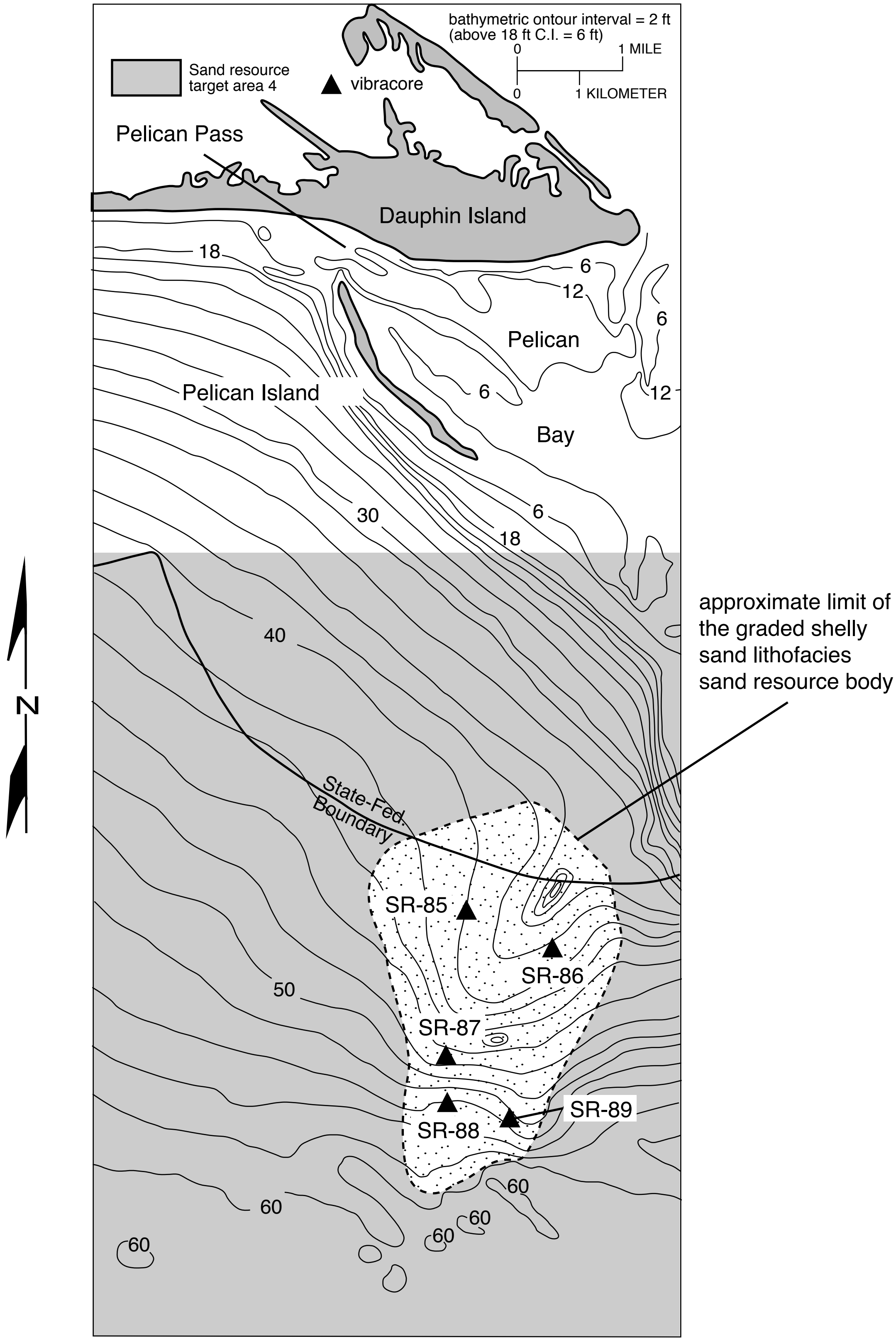


Figure 45.--Map of sand resource target area 4 showing locations of vibracores collected to measure Hurricane Danny mud layer thickness and distribution.

Table 7.--Summary of information pertaining to Hurricane Danny mud layer at sand resource target area 4

Vibracore Number	Core length (feet)	Pre-Hurricane Danny (predicted)			Post-Hurricane Danny (actual)		
		Facies	Lithology	Thickness (feet)	Facies	Lithology	Thickness (feet)
SR-85	6.6	SSS*	Sand	10	SM**	Sandy mud	2
SR-86	9.4	SSS	Sand	9	SSS	Sand	9
SR-87	10.9	SSS	Sand	11	SSS	Sand	9.9
SR-88	17.3	SSS	Sand	12	SSS	Sand	5.8
SR-89	14.9	SSS	Sand	9	SSS	Sand	13.3

*Surficial sand sheet lithofacies (SSS)

**Shelf mud lithofacies (SM) which at this vibracore site represents the Hurricane Danny mud layer.

Surficial sand sheet lithofacies directly underlies the shelf mud lithofacies in the vibracore.

SURVEYED BEACH PROFILES

As part of the present study, beach profiles were scheduled to be collected in November 1998 as part of the GSA's shoreline monitoring program and database of surveyed beach profiles. Unfortunately, Hurricane Georges caused extensive damage to the Alabama Gulf of Mexico shoreline on September 27, 1998. About 3 to 5 vertical and 50 lateral feet of dry beach was eroded away by the storm including much of the primary and secondary coastal dune fields. As a result of the hurricane, a storm beach profile was created in place of the normal summer beach profile.

The GSA surveyed the post-storm beaches at 21 Morgan Peninsula shoreline monitoring stations during November 18-20 and December 1-2, 1998. Eight Dauphin Island shoreline monitoring stations were surveyed December 8-10, 1998.

The beach profiles show the shoreface in a state of equilibrium with hurricane conditions, not normal summer or winter conditions. In addition, the profiles do not give a true measure of the net loss of beach due to the hurricane, because there will be some repair to the beach by natural processes as the shoreface changes toward equilibrium with the prevailing non-hurricane wave regime. Since Hurricane Georges occurred at the end of the summer wave regime and prior to the onset of the winter wave regime, opportunity for the beach to recover to the point of being able to measure the net loss of beach due to the hurricane is limited. The best time to collect a set of surveyed profiles would be near the end of summer 1999, after the summer wave regime has had a season to build beach to its annual maximum dry beach width. For these reasons, future work will include resurveying the beach at the 29 shoreline monitoring stations. A comparison will be made of the 1996, 1998, and 1999 beach profile data to determine the amount of beach eroded by the hurricane, how much beach was restored by natural processes, and the net loss of beach. The next set of surveyed beach profiles will enable an estimate to be made of the sand volume necessary to restore Morgan Peninsula Gulf of Mexico beaches.

SUMMARY

Vibracores and borings collected from the east Alabama inner continental shelf indicate that a Holocene transgressive fluvial-deltaic and marine-fill sequence overlies estuarine and fluvial-deltaic deposits of at least in part Pleistocene age. In addition, the data show that a southward dipping, late Pleistocene-early Holocene disconformity (last transgressive surface) was formed by erosion of these estuarine and fluvial-deltaic deposits during late Pleistocene and early Holocene regression and sea-level lowstand. Subsequently, north-south oriented networks of channels were incised into these deposits south of present-day Morgan Peninsula (ancestral Mobile-Tensaw and Perdido fluvial-deltaic systems).

Transgressive flooding of the east Alabama inner continental shelf between 10,000 and 6,000 years before present caused marine, fluvial-deltaic, and ebb-tidal delta sediments to be deposited over pre-Holocene estuarine and fluvial-deltaic deposits. As the rate of sea level rise decreased about 4,500 years before present the shoreline stood a few miles seaward of the present day shoreline. The decrease in the rate of sea level rise and the formation of the longshore drift system along the southern margin of Morgan Peninsula caused late Holocene barrier island development through vertical accretion and initiated and promoted ebb-tidal delta growth through vertical accretion and progradation. Sea level rise resulting in flooding of the remainder of the present day east Alabama inner continental shelf fostered deposition of mostly marine and ebb-tidal delta sediments - a process which continued uninterrupted throughout the late Holocene and continues today.

The lithofacies defined for the study area include shelf mud, surficial sand sheet, ebb-tidal delta (undifferentiated), delta front, channel sand, peat, marsh, levee, interdistributary bay, and pre-Holocene. Based on composition, grain size, and color, the SSS lithofacies is an excellent source of beach nourishment sand for Morgan Peninsula Gulf of Mexico beaches. In general, sediments of this lithofacies are white or gray in color, contain less than 5 percent mud, a trace of heavy minerals, and a sand-sized fraction averaging medium to coarse sand. The SSS lithofacies

is present in the study area as a massive sand sheet with associated shelf sand ridges and transverse bars. The upper surface of the sheet is exposed at the seafloor over 90 percent of the study area.

Alternative sources of beach nourishment sand could be obtained by recovering delta front and channel sand lithofacies. However, the relatively small volumes of sediment available, difficulty in physically accessing the deposits, and higher mud content (5 to 10 percent) make them less attractive as sources of beach nourishment sand compared to the SSS lithofacies.

Twelve geologic cross sections constructed through the study area indicate that sea-level rise and paleotopography controlled Holocene sedimentation. By mapping the pre-Holocene and Holocene sediments it is concluded that: (1) pre-Holocene deposits were incised by ancestral Perdido and Mobile-Tensaw fluvial-deltaic systems during late Pleistocene lowstand, (2) as sea level rose the paleochannels were partly backfilled with Holocene fluvial-deltaic sediments, (3) reworking of shelf sediments and formation of a longshore transport system in the present day nearshore Gulf of Mexico during late Holocene transgression produced a massive SSS lithofacies sand sheet with imbedded shelf sand ridges and transverse bars, (4) the SSS lithofacies completed infilling of paleochannels and buried Holocene deltaic deposits, (5) the ebb-tidal delta of Mobile Bay formed by vertical accretion and progradation during late Holocene transgression of the sea, and received coarse- and fine-grained sediments from the Mobile-Tensaw fluvial-deltaic system and by longshore drift (Hummell, 1996), (6) Holocene ebb-tidal delta of Mobile Bay sediments interfinger with Holocene fluvial-deltaic and SSS lithofacies sediments in the western quarter of the study area, (7) on the present-day east Alabama inner continental shelf, the Holocene section is thickest in paleochannels and thinnest over divides between paleochannels, and (8) pre-Holocene sediments penetrated by study area vibracores and borings are interpreted as mostly estuarine lithofacies of probable Pleistocene age.

Lithologic data from study area vibracores and borings was used to produce a series of isopach maps of the Holocene sediments in the east Alabama inner continental shelf. Variation in sediment thickness is associated with the presence of the ebb-tidal delta of Mobile Bay, paleochannels, paleochannel divides, shelf sand ridges, and transverse bars. The short length of some vibracores, especially in the shoreface zone, under estimates SSS lithofacies thickness.

Total estimated volume of SSS lithofacies in the study area was calculated to be 1.75 billion cubic yards - 0.564 billion and 1.18 billion cubic yards for state and federal waters, respectively. Sand resource area 1 contains an estimated 176 million cubic yards of SSS lithofacies. The estimated total volume of SSS lithofacies in sand resource area 2 was calculated to be 203 million cubic yards. An estimated volume of 330 million cubic yards was calculated for the SSS lithofacies in sand resource area 3.

With abundant sand resources available, beach nourishment borrow sites are constrained by the economics of the specific beach nourishment project, ship and gas industry infrastructure, historical and archaeological sites, sites of unexploded military ordnance, dredge material disposal sites, areas where the SSS lithofacies deposit is too thin, environmental concerns, and areas where the borrow site would not alter the wave climate and thereby cause or aggravate shoreline erosion and compromise shoreline storm protection.

Five vibracores collected from sand resource area 4 to measure the thickness and geographic distribution of a Hurricane Danny mud layer showed that the mud layer was present at only one core location and measured about 2 ft thick. In addition, the five vibracores showed that the thickness of the SSS lithofacies was reduced by erosion at some vibracore locations or increased at other locations by sediment deposition.

Hurricane Georges impacted coastal Alabama September 27, 1998, causing a storm surge of 8 to 10 ft and 15 in of rain. The storm caused extensive damage to the Alabama Gulf of Mexico shoreline, eroding about 3 to 5 vertical and 50 lateral feet of dry beach and much of the primary and secondary coastal dune fields. As a result of the hurricane, a storm beach profile was created in place of the normal summer beach profile.

The GSA surveyed the post-storm beaches at 29 shoreline monitoring stations. Future work will include resurveying the beach at the 29 shoreline monitoring stations during 1999. A comparison will be made of the 1996, 1998, and 1999 beach profile data to determine the amount of beach eroded by the hurricane, how much beach was restored by natural processes, and the net loss of beach.

REFERENCES CITED

Abston, J.R., Dinnel, S.P., Schroeder, W.W., Schultz, A.W., and Wiseman, W.J., Jr., 1987, Coastal sediment plume morphology and its relationship to environmental forcing: Main Pass, Mobile Bay, Alabama: American Society of Civil Engineers, Coastal Sediments 1987 Proceedings, p. 1989-2005.

Aigner, Thomas, 1985, Storm depositional systems: Berlin, Springer-Verlag, Lecture Notes in Earth Sciences, v. 3, 174 p.

Alabama Coastal Area Board, 1978, Alabama coastal area management program: A balanced approach to economic development and natural resource protection: Workshop Draft, 284 p.

April, G.C., and Hill, D.O., 1974, Water resources planning for rivers draining into Mobile Bay, Part I: Hydrodynamic and salinity models: Tuscaloosa, The University of Alabama, Bureau of Engineering Research Report 168-112, 73 p.

April, G.C., and Hu, S.A., 1979, Computer simulation of storm surges and river flooding in Mobile Bay: Tuscaloosa, The University of Alabama, Bureau of Engineering Research Report 232-112, 138 p.

April, G.C., and Lui, H.A., 1975, Water resources planning for rivers draining into Mobile Bay, Part II: Non-conservative species transport model: Tuscaloosa, The University of Alabama, Bureau of Engineering Research Report 185-112, 186 p.

April, G.C., and Ng, S.C., 1976a, Water resources planning for rivers draining into Mobile Bay, A users' manual for the two dimensional hydrodynamic model: Tuscaloosa, The University of Alabama, Bureau of Engineering Research Report 203-112, 100 p.

__1976b, Water resources planning for rivers draining into Mobile Bay, Part III: Sediment transport in Mobile Bay: Tuscaloosa, The University of Alabama, Bureau of Engineering Research Report 208-112, 140 p.

April, G.C., Hill, D.O., Liu, H.A., and Ng, S.A., 1975, Mobile Bay hydrodynamic and material transport mathematical modeling, *in* Vittor, B.A., ed., Proceedings of the remote sensing data users conference (December 4-5, 1975): Mobile Alabama, p. 53-90.

Bault, E.I., 1972, Hydrology of Alabama estuarine areas - cooperative Gulf of Mexico estuarine inventory: Alabama Marine Resources Bulletin 7, 25 p.

Boone, P.A., 1973, Depositional systems of the Alabama, Mississippi, and western Florida coastal zone: Gulf Coast Association of Geological Societies Transactions, v. 23, p. 266-277.

Brande, Scott, 1983, Seismic survey, geological stratigraphy, and dredge spoil studies of Mobile Bay region, Alabama: Mississippi-Alabama Sea Grant Consortium, Final report 1980-1983, Project no. R/ER- 6, 71 p.

Bridges, P.H., 1975, The transgression of a hard substrate shelf: the Llandovery (Lower Silurian) of the Welsh Borderland: Journal of Sedimentary Petrology, v. 45, p. 74-94.

Carlston, C.W., 1950, Pleistocene history of Coastal Alabama: Geological Society of America Bulletin, v. 61, p. 1119-1130.

Chermock, R.L., Boone, P.A., and Lipp, R.L., 1974, The environment of offshore and estuarine Alabama: Alabama Geological Survey Information Series 51, 135 p.

Christmas, J.Y., ed., 1973, Cooperative Gulf of Mexico estuarine inventory and study, Mississippi: Mississippi Gulf Coast Research Laboratory, 434 p.

Chuang, W-S., Schroeder, W.W., and Wiseman, W.J., Jr., 1982, Summer current observations off the Alabama coast: Contributions in Marine Science, v. 25, p. 121-131.

Coleman, S.M., Halka, J.P., Hobbs, C.H., III, Mixon, R.B., and Foster, D.S., 1990, Ancient channels of the Susquehanna River beneath Chesapeake Bay and the Delmarva Peninsula: Geological Society of America Bulletin, v. 102, no. 9, p. 1268-1279.

Cotter, E., 1975, Deltaic deposits in the Upper Cretaceous Ferron Sandstone, Utah, *in* Broussard, M.L., ed., Deltas, Models for Exploration: Houston, Texas, Houston Geological Society, p. 471-484.

Cowardin, L.M., Carter, Virginia, Golet, F.C., and Laroe, E.T., 1979, Classification of wetlands and deepwater habitats of the United States: Washington, D.C., U.S. Government Printing Office, Publication FWS/OBSS-79-31, 103 p.

Crance, J.H., 1971, Description of Alabama estuarine areas: Alabama Marine Resources Bulletin 6, 85 p.

Davis, R.A., and Klay, J.M., 1989, Origin and development of Quaternary terrigenous inner shelf sequences, southwest Florida: Gulf Coast Association of Geological Societies Transactions, v. 39, p. 341-347.

Dinnel, S.P., 1988, Circulation and sediment dispersal on the Louisiana-Mississippi-Alabama continental shelf: Louisiana State University, unpublished Ph.D. dissertation, 173 p.

Dinnel, S.P., Schroeder, W.W., and Wiseman, W.J., Jr., 1990, Estuarine-shelf exchange using Landsat images of discharge plumes: Journal of Coastal Research, v. 6, p. 789-799.

Donoghue, J.F., 1989, Sedimentary environments of the inner continental shelf, northeastern Gulf of Mexico: Gulf Coast Association of Geological Societies Transactions, v. 39, p. 355-363.

Doyle, L.J., and Sparks, T.N., 1980, Sediments of the Mississippi, Alabama and Florida (MAFLA) continental shelf: Journal of Sedimentary Petrology, v. 50, p. 905-916.

Droser, M.L., and Bottjer, D.J., 1986, A semiquantitative field classification of ichnofabric: Journal of Sedimentary Petrology, v. 56, p. 558-559.

Drummond, S.E., Jr., and Stow, S.H., 1979, Hydraulic differentiation of heavy minerals, offshore Alabama and Mississippi: Geological Society of America Bulletin, v. 90, no. 9, p. 1429-1457.

Fletcher, C.H., Knebel, H.J., and Kraft, J.C., 1990, Holocene evolution of an estuarine coast and tidal wetlands: Geological Society of America Bulletin, v. 102, p. 283-297.

Foxworth, R.D., Priddy, R.R., Johnson, W.B., and Moore, W.S., 1962, Heavy minerals from recent beaches of the Gulf coast of Mississippi and associated islands: Mississippi Geological Survey Bulletin 93, 92 p.

Friedman, G.M., and Sanders, J.E., 1978, Principles of sedimentology: New York, John Wiley and Sons, p. 792.

Garcia, A.W., 1977, Dauphin Island littoral transport calculations: U.S. Army Corps of Engineers Waterways Experiment Station Miscellaneous Paper H-77-11, 12 p.

Hardin, J.D., Sapp, C.D., Emplaincourt, J.L., and Richter, K.E., 1976, Shoreline and bathymetric changes in the coastal area of Alabama, a remote-sensing approach: Alabama Geological Survey Information Series 50, 125 p.

Hennessy, J.T., and Zarillo, G.A., 1987, The interrelation and distinction between flood-tidal delta and washover deposits in a transgressive barrier island: Marine Geology, v. 78, p. 35-56.

Hoyt, W.H., and Damarest, J.M., 1981, Vibracoring in coastal environments, *in* Hoyt, W.H., and Damarest, J.M., eds., Vibracoring in coastal environments: The R.V. *Phryne* II Barge and associated coring methods: Newark, Delaware, University of Delaware Sea Grant College Program no. DEL-SG-01-81, p. 20-30.

Hubbard, D.K., Oertel, George, and Nummedal, Dag, 1979, The role of waves and tidal currents in the development of tidal-inlet sedimentary structures and sand body geometry examples from North Carolina, South Carolina and Georgia: Journal of Sedimentary Petrology, v. 49, no. 4, p. 1073-1092.

Hummell, R.L., 1996, Holocene geologic history of the west Alabama inner continental shelf, Alabama: Alabama Geological Survey Circular 189, 131 p.

__1998, Characterization of an offshore sand resource site for use in beach nourishment projects on Dauphin Island, Alabama: Gulf Coast Association of Geological Societies Transactions, v. 48, p. 119-128.

Hummell, R.L., and Parker, S.J., 1995a, Holocene geologic history of Mississippi Sound, Alabama: Alabama Geological Survey Circular 185, 91 p.

__1995b, Holocene geologic history of Mobile Bay, Alabama: Alabama Geological Survey Circular 186, 97 p.

Hummell, R.L., and Smith, W.E., 1995, Geologic and environmental characterization and near-term lease potential of an offshore sand resource site for use in beach nourishment projects on Dauphin Island, Alabama: Alabama Geological Survey, Minerals Management Service cooperative agreement no. 14-35-0001-30725, Draft Annual Report, 165 p. + 28 p. appendix.

__1996, Geologic resource delineation and hydrographic characterization of an offshore sand resource site for use in beach nourishment projects on Dauphin Island, Alabama: Alabama Geological Survey, Minerals Management Service cooperative agreement no. 14-35-0001-30781, Draft Annual Report, 169 p. + 38 p. appendix.

Hsu, K.J., 1960, Texture and mineralogy of recent sands of the Gulf Coast: Journal of Sedimentary Petrology, v. 30, no. 3, p. 380-403.

Isphording, W.C., Springfellow, J.A., and Flowers, G.C., 1985, Sedimentary and geochemical systems in transitional marine sediments in the northeastern Gulf of Mexico: Gulf Coast Association of Geological Societies Transactions, v. 35, p. 397-408.

Israel, A.M., Ethridge, F.G., and Estes, E.L., 1987, A sedimentologic description of a microtidal, flood-tidal delta, San Luis Pass, Texas: Journal of Sedimentary Petrology, v. 57, no. 2, p. 288-300.

Johnson, H.D., 1978, Shallow siliciclastic seas, *in* Reading, H.G., ed., Sedimentary environments and facies: New York, Elsevier, p. 207- 258.

Kindinger, J.L., 1988, Seismic stratigraphy of the Mississippi-Alabama shelf and upper continental slope: Marine Geology, v. 83, p. 79-94.

Kindinger, J.L., Balson, P.S., and Flocks, J. G., 1994, Stratigraphy of the Mississippi-Alabama shelf and the Mobile River incised-valley system: *in* Dalrymple, R.W., Boyd, Ron, and Zaitlin, B.A., eds., Incised-valley systems: origin and sedimentary sequences: Society of Economic Paleontologists and Mineralogists Special Publication no. 51, p. 83-95.

Kindinger, J.L., Miller, R.J., Stelting, C.E., and Bouma, A.H., 1982, Depositional history of Louisiana-Mississippi outer continental shelf: U.S. Geological Survey Open-File Report 82-1077, 48 p.

Kindinger, J.L., Penland, Shea, Williams, S.J., and Suter, J.R., 1989, Inner shelf deposits of the Louisiana-Mississippi-Alabama region, Gulf of Mexico: Gulf Coast Association of Geological Societies Transactions, v. 39, p. 413-420.

Kindinger, J.L., Penland, Shea, Williams, S.J., Suter, J.R., McBride, R.A., Brooks, G.R., and Locker, S., 1991, Nearshore Holocene stratigraphy, northern Gulf of Mexico: integration of regional geologic studies: *in* Coastal depositional systems in the Gulf of Mexico, Quaternary framework and environmental issues: Gulf Coast Section, Society of Economic Paleontologists and Mineralogists Foundation, Twelfth Annual Research Conference, Program with Abstracts, p. 96-102.

Kjerfve, Björn, 1983, Analysis and synthesis of oceanographic conditions in Mississippi Sound, April-October, 1980: U.S. Army Corps of Engineers, Mobile District, Final Report, Contract DACW01-82-Q-0022, 438 p.

Kjerfve, Björn., and Sneed, J.E., 1984, Analysis and synthesis of oceanographic conditions in the Mississippi Sound offshore region: U.S. Army Corps of Engineers, Mobile District, Final Report, v. 1 and II, Contract DACW 01-83-R-0014, 253 p.

Kraft, J.C., 1971, Sedimentary facies patterns and geologic history of a Holocene marine transgression: Geological Society of America Bulletin, v. 82, p. 2131-2158.

Lockwood, Millington, and McGregor, B.A., 1988, Proceedings of the 1987 exclusive economic zone symposium on mapping and research: Planning for the next 10 years: U.S. Geological Survey Circular 1018, 175 p.

Ludwick, J.C., 1964, Sediments in the northeastern Gulf of Mexico, *in* Miller, R.L., ed., Papers in marine geology: New York, MacMillan Co., p. 208-238.

Maldonado, A., 1975, Sedimentation, stratigraphy, and development of the Ebro Delta, Spain, *in* Broussard, M.L., ed., Deltas, Models for Exploration: Houston, Texas, Houston Geological Society, p. 311-338.

McBride, R.A, 1997, Seafloor morphology, geologic framework, and sedimentary processes of a sand-rich shelf offshore Alabama and northwest Florida: northeastern Gulf of Mexico: Louisiana State University, unpublished Ph.D. dissertation, 509 p.

McBride, R.A., and Byrnes, M.R., 1995, Surficial sediments and morphology of the southwestern Alabama/western Florida Panhandle coast and shelf: Gulf Coast Association of Geological Societies Transactions, v. 45, p. 392-404.

McBride, R.A., Byrnes, M.R., Anderson, L.C., and Sen Gupta, B.K., 1996, Holocene and late Pleistocene sedimentary facies of a sand-rich continental shelf: a standard section for the northeastern Gulf of Mexico: Gulf Coast Association of Geological Societies Transactions, v. 46, p. 287-299.

__1997, Late Quaternary stratigraphic architecture of a sand-rich shelf and the origin of linear shoals: northeastern Gulf of Mexico: American Association of Petroleum Geology, Official Program 1997 Annual Convention, v. 6, p. A79.

McBride, R.A., Byrnes, M.R., Penland, Shea, Pope, D.L., and Kindinger, J.L., 1991, Geomorphic history, geologic framework, and hard mineral resources of the Petit Bois Pass Area, Mississippi-Alabama, *in* Coastal depositional systems in the Gulf of Mexico, Quaternary framework and environmental issues: Gulf Coast Section, Society of Economic Paleontologists and Mineralogists Foundation, Twelfth Annual Research Conference, Program with Abstracts, p. 116-127.

McFarlan, Edward, Jr., and LeRoy, D.O., 1988, Subsurface geology of the Late Tertiary and Quaternary deposits, coastal Louisiana and the adjacent continental shelf: Gulf Coast Association of Geological Societies Transactions, v. 38, p. 421-433.

Meisburger, E.P., Williams, S.J., and Prins, D.A., 1980, An apparatus for cutting core liners: Journal of Sedimentary Petrology, v. 50, p. 641-642.

Mettee, M.F., O'Neil, P.E., Pierson, J.M., and Suttkus, R.D., 1989, Fishes of the western Mobile River basin in Alabama and Mississippi: Geological Survey of Alabama Atlas 24, 170 p.

Milliman, J.D., and Emery, K.O., 1968, Sea-levels during the past 35,000 years: Science, v. 162, p. 1121-1123.

Murray, S.P., 1976, Currents and circulation in the coastal waters of Louisiana: Louisiana State University, Baton Rouge, Louisiana, Technical Report 210, 41 p.

National Oceanic and Atmospheric Administration, 1991a, Nautical chart, Mississippi Sound and approaches, Dauphin Island to Cat Island, No. 11373, 1:80,000: Washington, D.C., NOAA, National Ocean Survey, 1 sheet.

__1991b, Nautical chart, Mobile Bay, No. 11376, 1:80,000: Washington, D.C., NOAA, National Ocean Survey, 1 sheet.

__1991c, Nautical chart, Pensacola Bay and approaches, No. 11382, 1:80,000: Washington, D.C., NOAA, National Ocean Survey, 1 sheet.

Neumann, C.C., Cry, E.C., and Jarvinen, B.J., 1981, Tropical Cyclones of the North Atlantic Ocean, 1871-1980. National Climate Center, 23 p.

Oertel, G.F., 1973, Examination of textures and structures of mud in layered sediments at the entrance of a Georgia tidal inlet: Journal of Sedimentary Petrology, v. 43, p. 33-41.

Otvos, E.G., 1975, Late Pleistocene transgressive unit (Biloxi Formation), northern Gulf coast: American Association of Petroleum Geologists Bulletin, v. 59, p. 148-154.

__1976, Mississippi offshore inventory and geological mapping project: Mississippi Marine Research Council, Long Beach, Mississippi, 27 p.

__1986, Stratigraphy and potential economic sand resources of the Mississippi-Alabama barrier island system and adjacent offshore areas: Mississippi Mineral Resources Institute Open File Report 86-1F, 67 p.

Parker, S.J., 1990, Assessment of nonhydrocarbon mineral resources in the exclusive economic zone in offshore Alabama: Alabama Geological Survey Circular 147, 73 p.

Parker, S.J., Davies, D.J., and Smith, W.E., 1997, Geological, economic, and environmental characterization of selected near-term leasable offshore sand deposits and competing onshore sources for beach nourishment: Alabama Geological Survey Circular 190, 173 p.

Pyle, T.E., Henry, V.J., McCarthy, J.C., Giles, R.T., and Neurauter, T.W., 1975, Baseline monitoring studies, Mississippi, Alabama, Florida outer continental shelf, 1975-1976: Washington, D.C., Bureau of Land Management, Geophysical investigations for biolithologic mapping of the MAFLA-OCS lease area, Volume 5, BLM/ST-78/34, 267 p.

Raney, D.C., 1984, A depth-averaged water quality model and application to salinity propagation in Mobile Bay: Tuscaloosa, The University of Alabama, Bureau of Engineering Research Report 297-122, 41 p.

__1985, Numerical computations for estuarine flood plains: Northeast Gulf Science, v. 7, p. 127-138.

Raney, D.C., and Youngblood, J.N., 1987, Numerical modeling of salinity propagation in Mobile Bay, *in* Lowery, T.A., ed., Symposium on the natural resources of the Mobile Bay estuary, Mississippi-Alabama Sea Grant Consortium MASGP-87-007, p. 148-151.

Raney, D.C., April, G.C., Livings, Joel, and Raney, D.C., II, 1989a, Hourly velocity vector plots for average monthly conditions in Mobile Bay: Tuscaloosa, The University of Alabama, Bureau of Engineering Research Report 459-183, 291 p.

__1989b, Hourly salinity contours for average monthly conditions in Mobile Bay: Tuscaloosa, The University of Alabama, Bureau of Engineering Research Report 458-183, 291 p.

Raney, D.C., Youngblood, J.N., and April, G.C., 1984, Hydrodynamics of Mobile Bay and Mississippi Sound: Tuscaloosa, The University of Alabama, Bureau of Engineering Research Report 324-183, 128 p.

Raymond, D.E., Copeland, C.W., and Rindsberg, A.K., 1993, Post-Miocene sediments of the shallow subsurface of coastal Alabama: Alabama Geological Survey Circular 168, 93 p.

Reed, J.C., 1988, Correlation of Cenozoic sediments on the Gulf of Mexico OCS: Oil and Gas Journal, v. 86, no. 1, p. 54-59.

Reineck, H.-E., and Singh, I.B., 1986, Depositional sedimentary environments: New York, Springer-Verlag, 551 p.

Rucker, J.B., and Snowden, J.O., 1989, Relict progradational beach ridge complex on Cat Island in Mississippi Sound: Gulf Coast Association of Geological Societies Transactions, v. 39, p. 531-539.

Ryan, J.J., 1969, A sedimentologic study of Mobile Bay: Florida State University Department of Geology Contribution no. 30, 110 p.

Ryan, J.J., and Goodell, H.G., 1972, Contemporary sediments, Part 1 of Marine geology and estuarine history of Mobile Bay, Alabama, *in* Nelson, B.W., ed., Environmental framework of coastal plain estuaries: Geological Society of America Memoir 133, p. 517-554.

Schroeder, W.W., 1976, Physical environmental atlas of coastal Alabama: Mississippi-Alabama Sea Grant Consortium MASGP-76-034, 275 p.

__1977, Sea truth and environmental characterization studies of Mobile Bay, Alabama, utilizing ERTS-1 data collection platforms: Remote Sensing of Environment, v. 6, p. 27-43.

Schroeder, W.W., and Wiseman, W.J., Jr., 1986, Low-frequency shelf estuarine exchange processes in Mobile Bay and estuarine systems on the northern Gulf of Mexico: *in* Wolfe, D.A., ed., Estuarine Variability: New York, Academic Press, Inc., p. 355-367.

Schroeder, W.W., Dinnell, S.P., Wiseman, W.J., Jr., and Merrell, W.J., Jr., 1987, Circulation patterns inferred from the movement of detached bouys in eastern Gulf of Mexico: Continental Research, v. 7, p. 883-894.

Schroeder, W.W., Huh, O.K., Rouse, L.J., Jr., and Wiseman, W.J., Jr., 1985, Satellite observations of the circulation east of the Mississippi Delta: cold air outbreak conditions: Remote Sensing of Environment, v. 18, p. 49-58.

Seim, H.E., Kjerfve, Björn, and Sneed, J.E., 1987, Tides of Mississippi Sound and the adjacent continental shelf: Estuarine, Coastal and Shelf Science, v. 25, p. 143-156.

Sha, L.P., 1989, Holocene-Pleistocene interface and three-dimensional geometry of the ebb-delta complex, Texel Inlet, The Netherlands: Marine Geology, v. 89, p. 207-228.

Smith, W.E., 1986, Geomorphology of Coastal Baldwin County, Alabama: Alabama Geological Survey Bulletin 124, 86 p.

__1988, Geomorphology of the Mobile delta: Alabama Geological Survey Bulletin 132, 133 p.

Stephen, M.F., and Gorsline, D.S., 1975, Sedimentary aspects of the New River Delta, Salton Sea, Imperial County, California, *in* Broussard, M.L., ed., Deltas, Models for Exploration: Houston, Texas, Houston Geological Society, p. 267-282.

Stow, S.H., Drummond, S.E., and Haynes, C.D., 1975, Occurrence and distribution of heavy minerals, offshore Alabama and Mississippi: Society of Mining Engineers-AIME Transactions, v. 260, p. 75-77.

Stumpf, R.P., and Gelfenbaum, Guy, 1990, Effects of high river discharge on suspended sediments in Mobile Bay, Alabama: EOS, v. 71, p. 1406-1407.

Stumpf, R.P., and Pennock, J.R., 1989, Calibration of a general optical equation for remote sensing of suspended sediments in a moderately turbid estuary: Journal of Geophysical Research, v. 94, p. 14363-14371.

Suter, J.R., Berryhill, H.L., Jr., and Penland, Shea, 1985, Environments of sand deposition, southwest Louisiana continental shelf: Gulf Coast Association of Geological Societies Transactions, v. 35, p. 495-503.

Swift, D.J.P., 1976, Continental sedimentation, *in* Stanley, D.J., and Swift, D.J.P., Jr., eds., Marine sediment transport and environmental management: New York, John Wiley and Sons, p. 225-310.

Swift, D.J.P., Stanley, D.J., and Curray, J.R., 1971, Relict sediments on continental shelves: A reconsideration: Journal of Geology, v. 79, p. 322-346.

TerEco Corporation, 1979, Literature review of Mississippi Sound and adjacent area: Mobile District, U.S. Army Corps of Engineers, Final Report, Contract DAC1-78-C-0244, 251 p.

Tolbert, W.H., and Salsman, G.G., 1964, Surface circulation of the eastern Gulf of Mexico as determined by drift bottle studies: Journal of Geophysical Research, v. 69, p. 223-230.

Trewartha, G.T., and Horn, L.H., 1980, An Introduction to Climate: New York, McGraw-Hill, p. 273-283.

U.S. Army Corps of Engineers, 1955, Perdido Pass (Alabama Point) Alabama, beach erosion control study: Washington, D.C., U.S. Government Printing Office, 757 p.

__1979, Draft Technical report on Mobile Harbor, Alabama: Mobile District, U. S. Army Corps of Engineers, 757 p.

__1981, Hurricane Frederic post disaster report 30 August-14 September 1979: Mobile District, U. S. Army Corps of Engineers, 251 p.

__1984, Exploration and production of hydrocarbon resources in coastal Alabama and Mississippi: Mobile District, U.S. Army Corps of Engineers, 615 p.

U.S. Department of the Navy, 1986, Draft environmental impact statement United States Navy: Gulf Coast Strategic Homeporting: Mobile, Alabama, Appendix V.

Upshaw, C.F., Creath, W.B., and Brooks, F.L., 1966, Sediments and microfauna off the coast of Mississippi and adjacent states: Mississippi Geological Survey Bulletin 106, 127 p.

Van Andel, T.H., and Poole, D.M., 1960, Sources of recent sediments in the northern Gulf of Mexico: Journal of Sedimentary Petrology, v. 30, p. 91-122.

Van Wagoner, J.C., Posamentier, H.W., Mitchum, R.M., Vail, P.R., Sarg, J.F., Loutit, T.S., and Hardenbol, Jan, 1988, An overview of the fundamentals of sequence stratigraphy and key definitions, *in* Wilgus, C.K., Posamentier, H.W., Ross, C.A., and Kendall, C.G.St.C., eds., Sea-level changes: An integrated approach: Society of Economic Paleontologists and Mineralogists Special Publication no. 42, p. 39-45.

Vittor, B.A., and Associates, Inc., 1985, Tuscaloosa trend regional data search and synthesis (volume 1-synthesis report): New Orleans, Louisiana, Minerals Management Service, contract no. 14-12-001-30048, Final Report, 477 p.

Wiseman, W.J., Jr., 1986, Estuarine-shelf interactions, *in* Mooers, C.N.K., ed., Barotropic processes on continental shelves: Coastal and Estuarine Sciences, v. 3, p. 109-115.

Wiseman, W.J., Jr., Schroeder, W.W., and Dinnel, S.P., 1988, Shelf-estuarine water exchanges between the Gulf of Mexico and Mobile Bay, Alabama: American Fisheries Society Symposium, v. 3, p. 1-8.

Woolsey, J.R., 1984, Exploration for industrial minerals in Mississippi Sound and adjacent offshore territories of Mississippi and Alabama: Mississippi-Alabama Sea Grant Consortium, MASGP-83-019, 21 p.

APPENDIX A

COLUMNAR SECTIONS OF

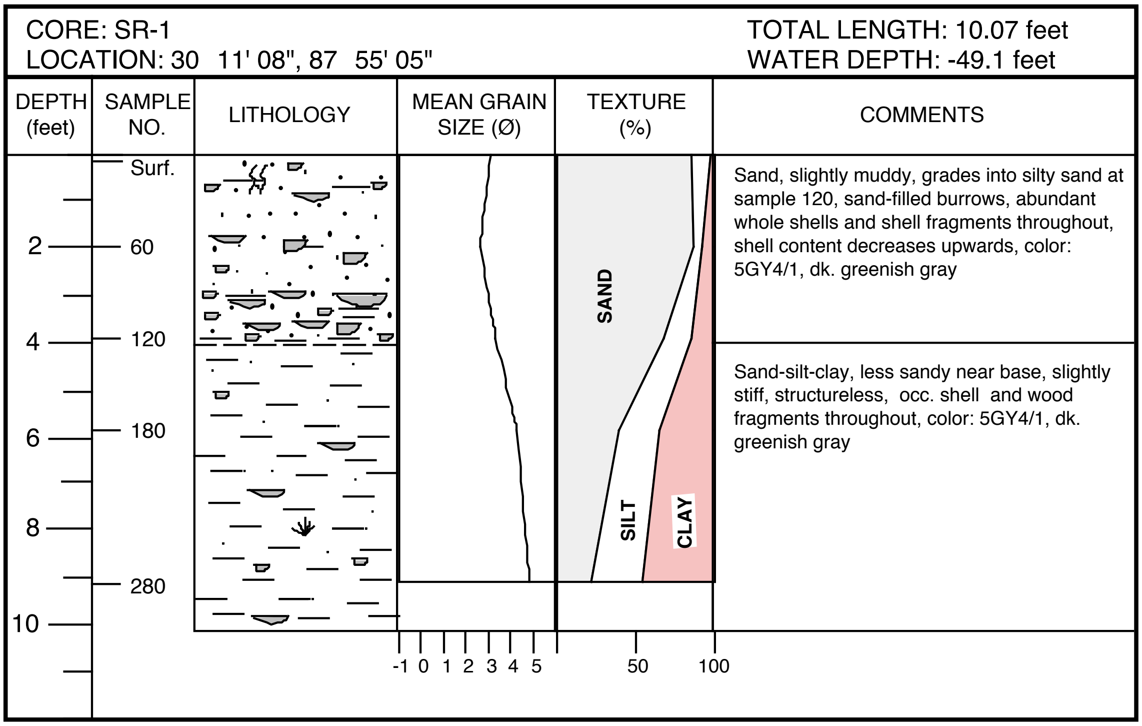
VIBRACORES AND FOUNDATION BORINGS

See figure 14 for locations

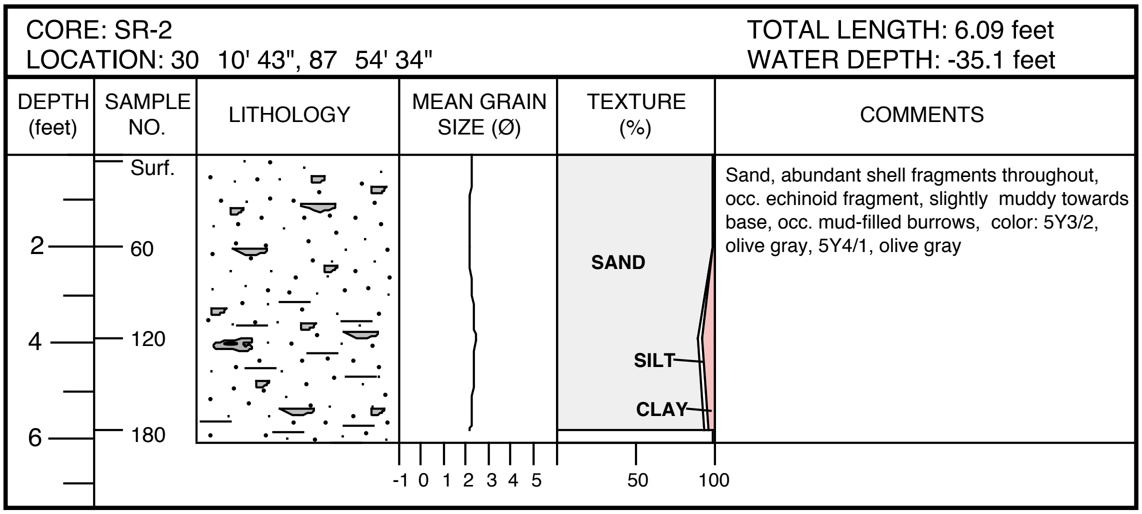
See appendix B for explanation of patterns and symbols

used in columnar sections

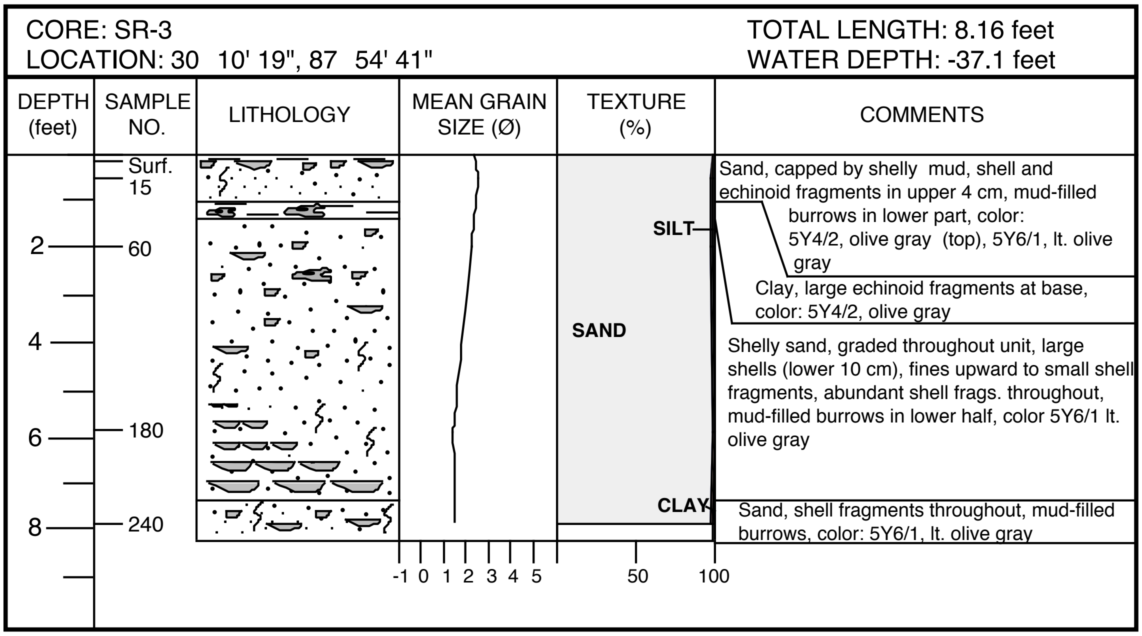
Page



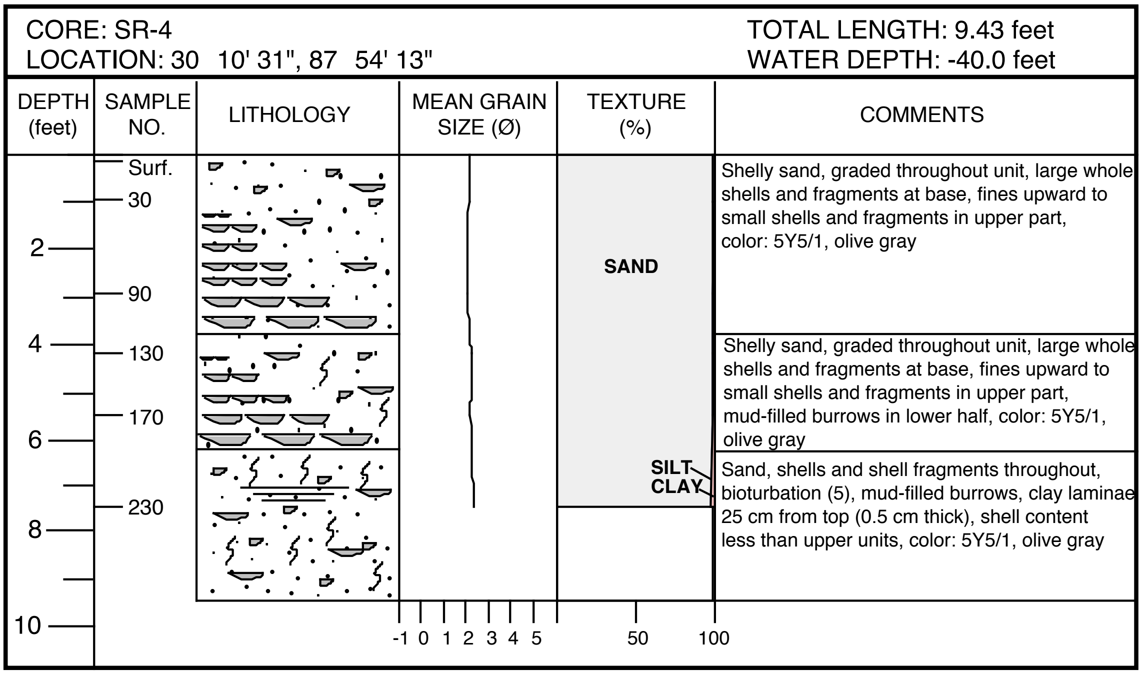
A-1.--Columnar section of EEZ vibracore SR-1 (modified from Parker and others, 1997).



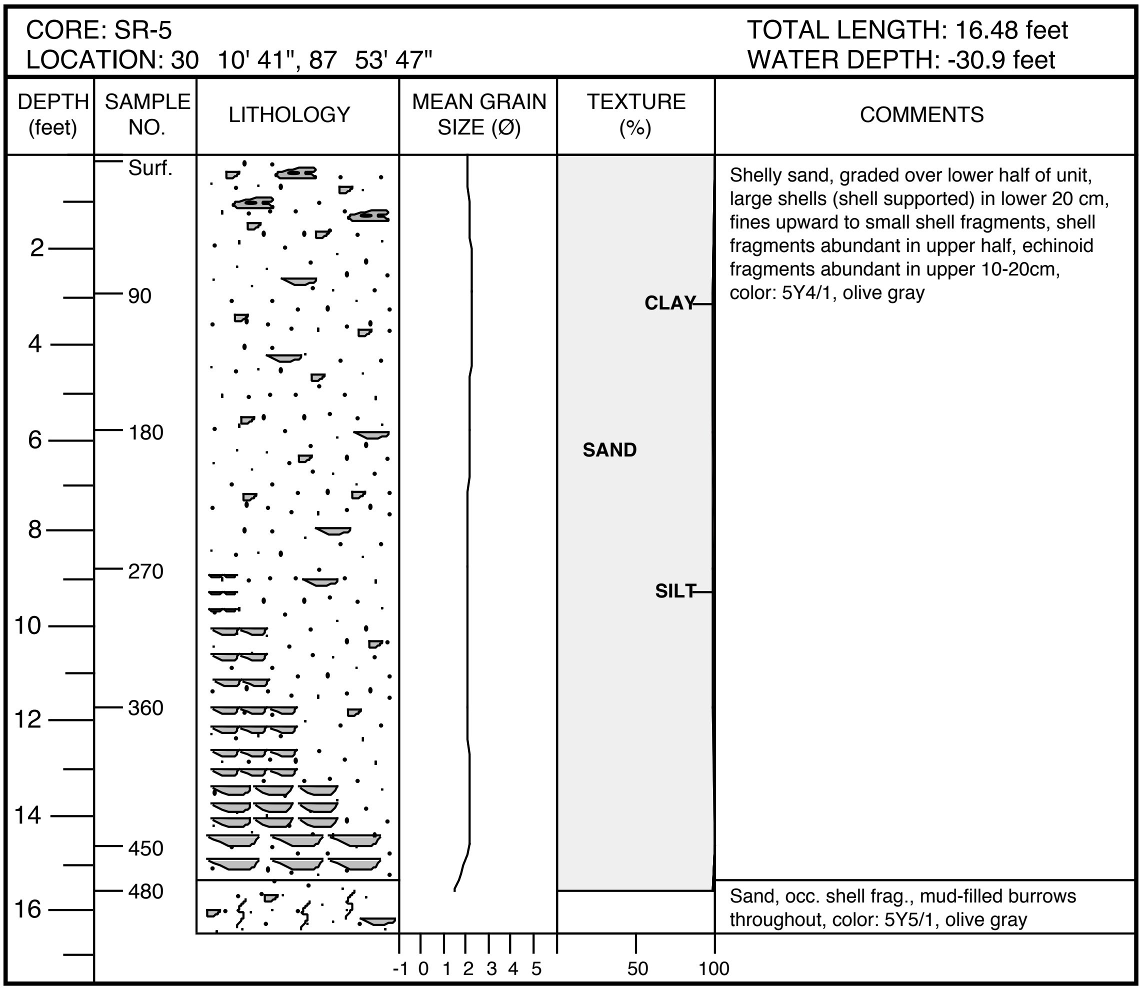
A-2.--Columnar section of EEZ vibracore SR-2 (modified from Parker and others, 1997).



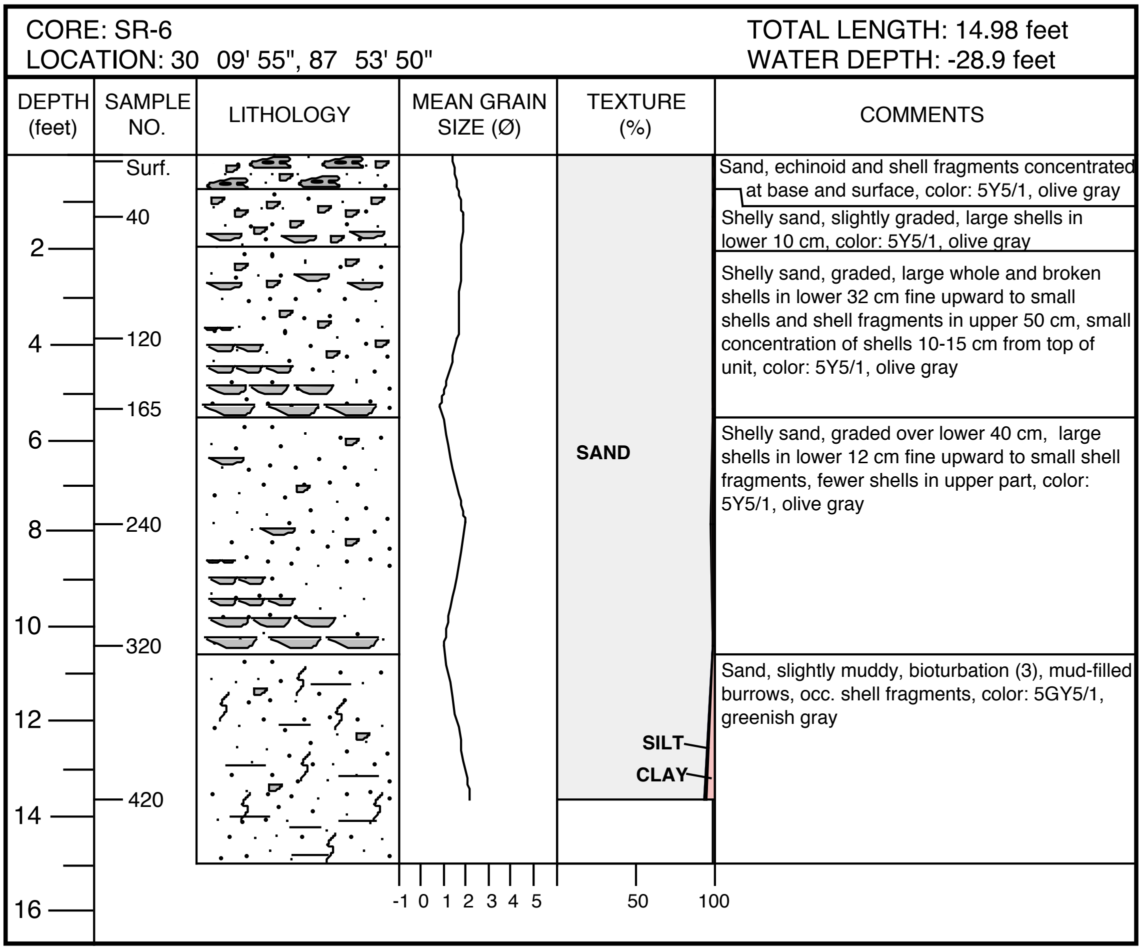
A-3.--Columnar section of EEZ vibracore SR-3 (modified from Parker and others, 1997).



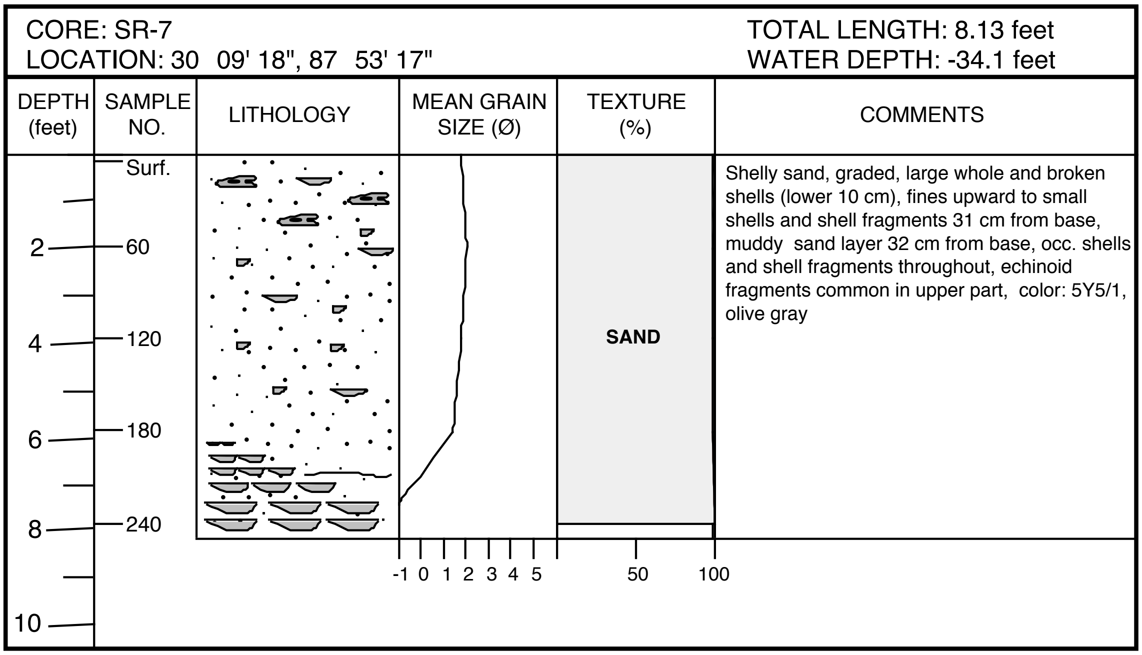
A-4.--Columnar section of EEZ vibracore SR-4 (modified from Parker and others, 1997).



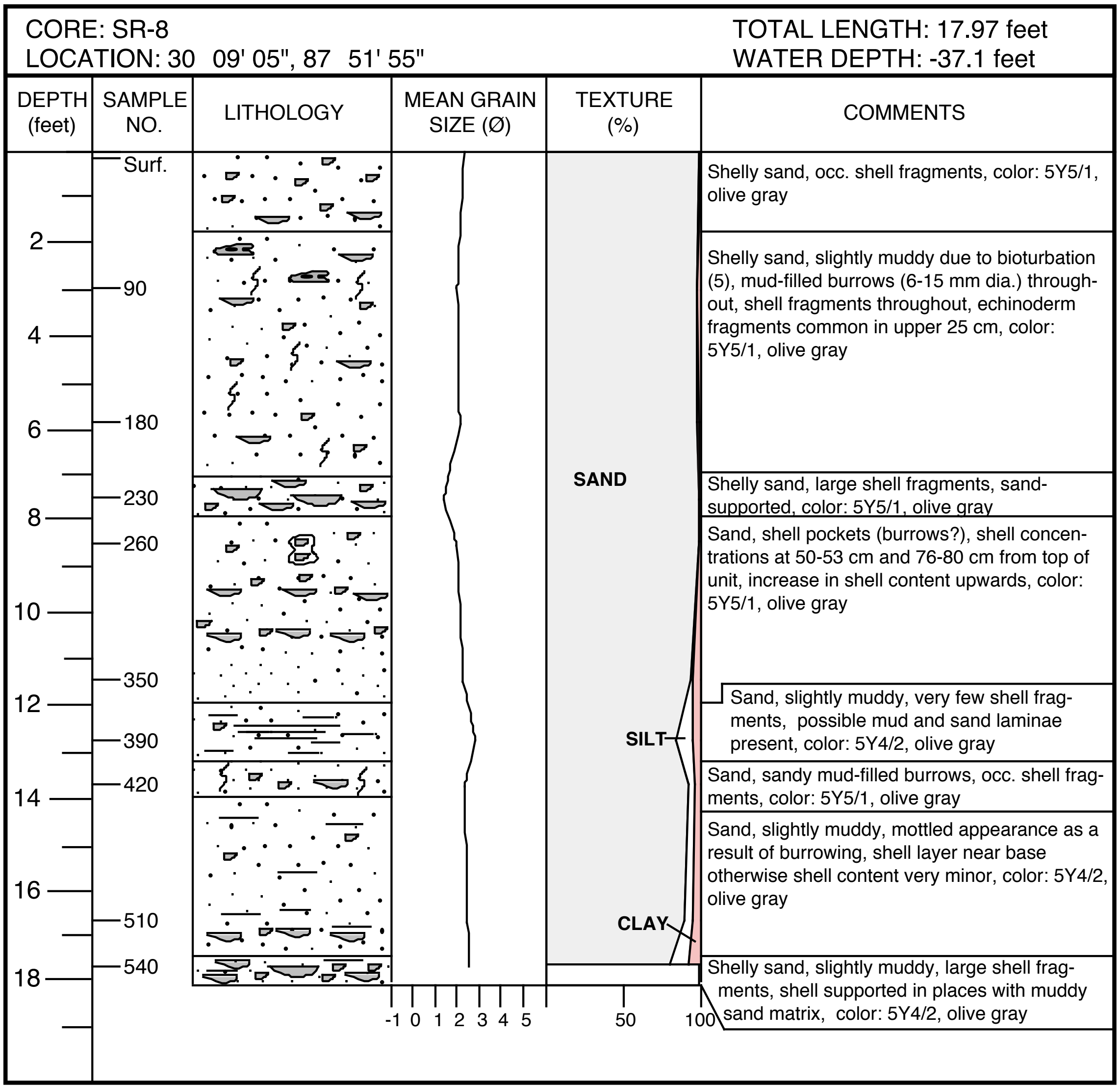
A-5.--Columnar section of EEZ vibracore SR-5 (modified from Parker and others, 1997).



A-6.--Columnar section of EEZ vibracore SR-6 (modified from Parker and others, 1997).



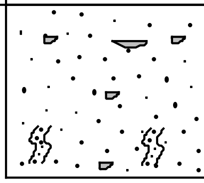
A-7.--Columnar section of EEZ vibracore SR-7 (modified from Parker and others, 1997).



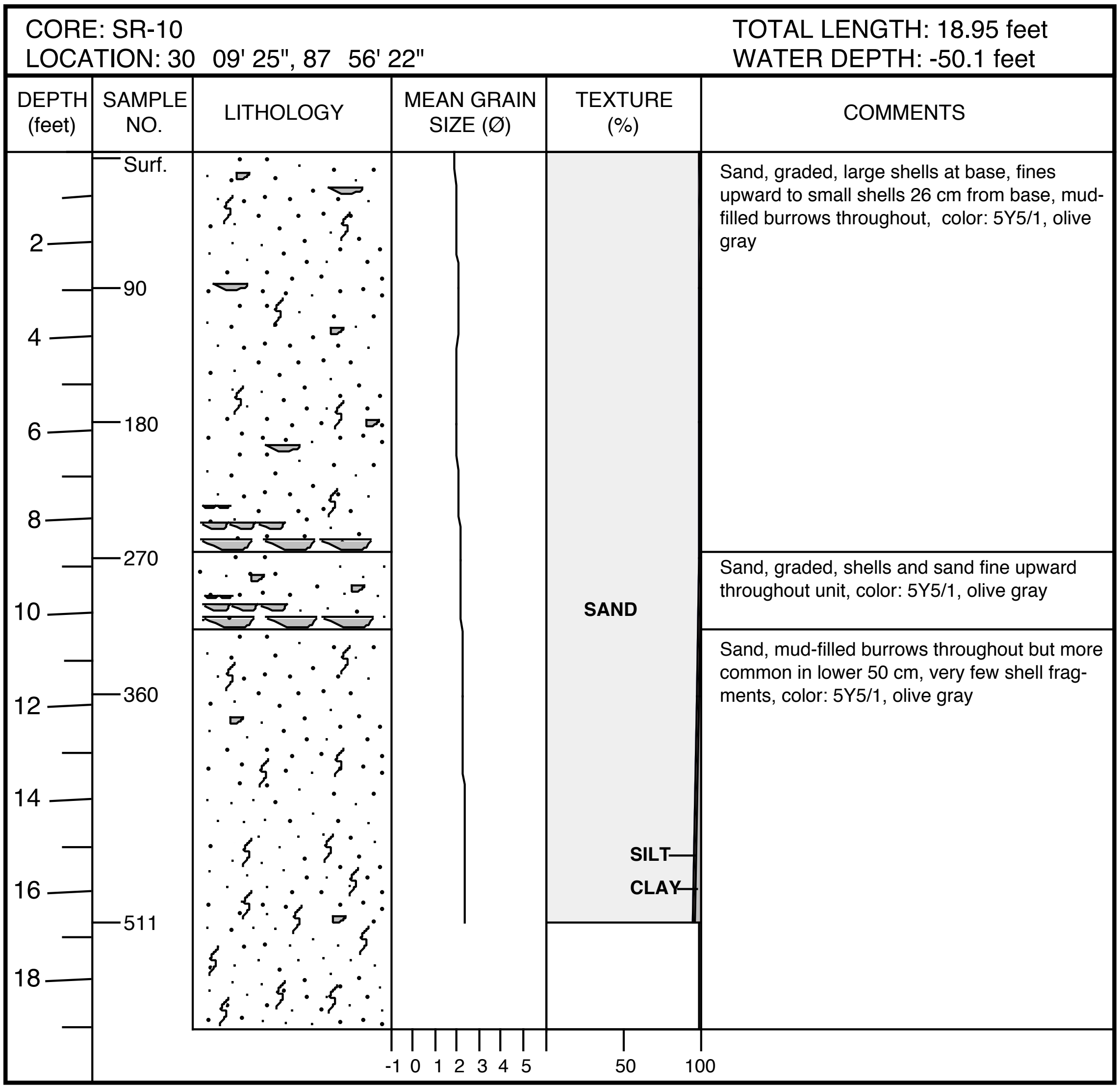
A-8.--Columnar section of EEZ vibracore SR-8 (modified from Parker and others, 1997).

CORE: SR-9
LOCATION: 30 08' 27", 87 58' 16"

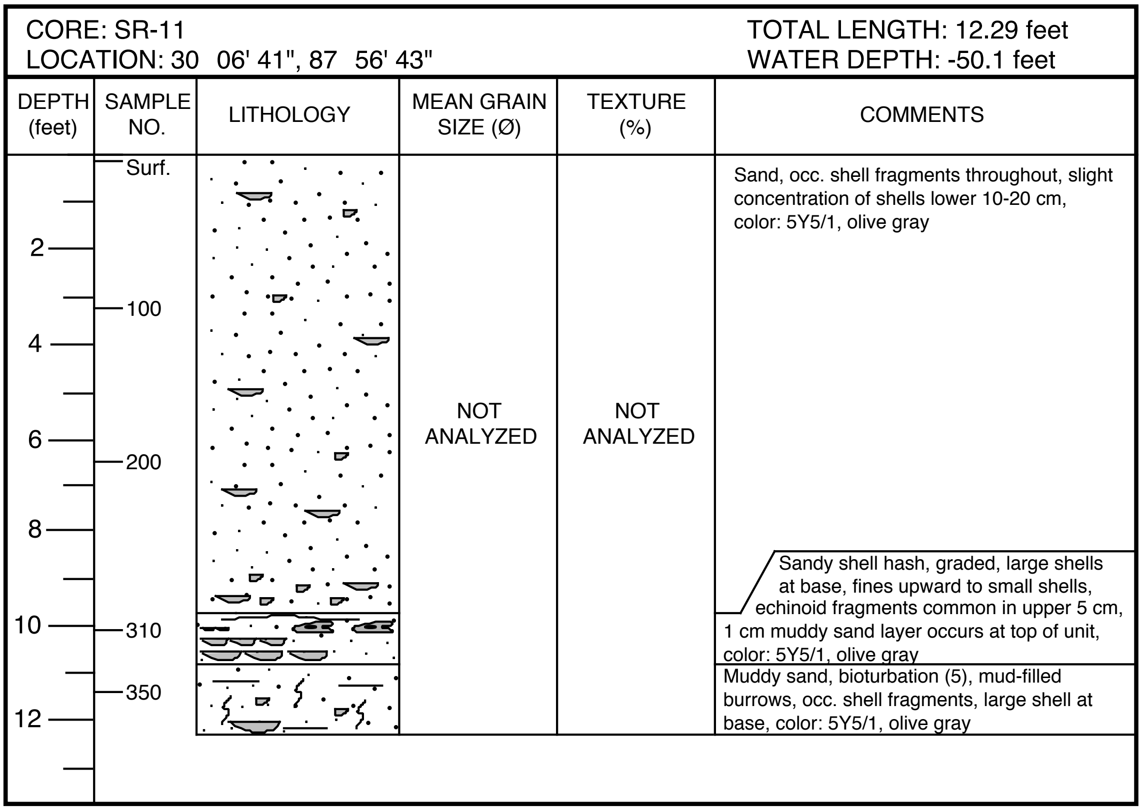
TOTAL LENGTH: 3.64 feet
WATER DEPTH: -47.1 feet

DEPTH (feet)	SAMPLE NO.	LITHOLOGY	MEAN GRAIN SIZE (Ø)	TEXTURE (%)	COMMENTS
2 4	Surf. 60		NOT ANALYZED	NOT ANALYZED	Sand, occ. small shell fragments throughout, sand-filled burrows near base, color: 5Y5/1, olive gray

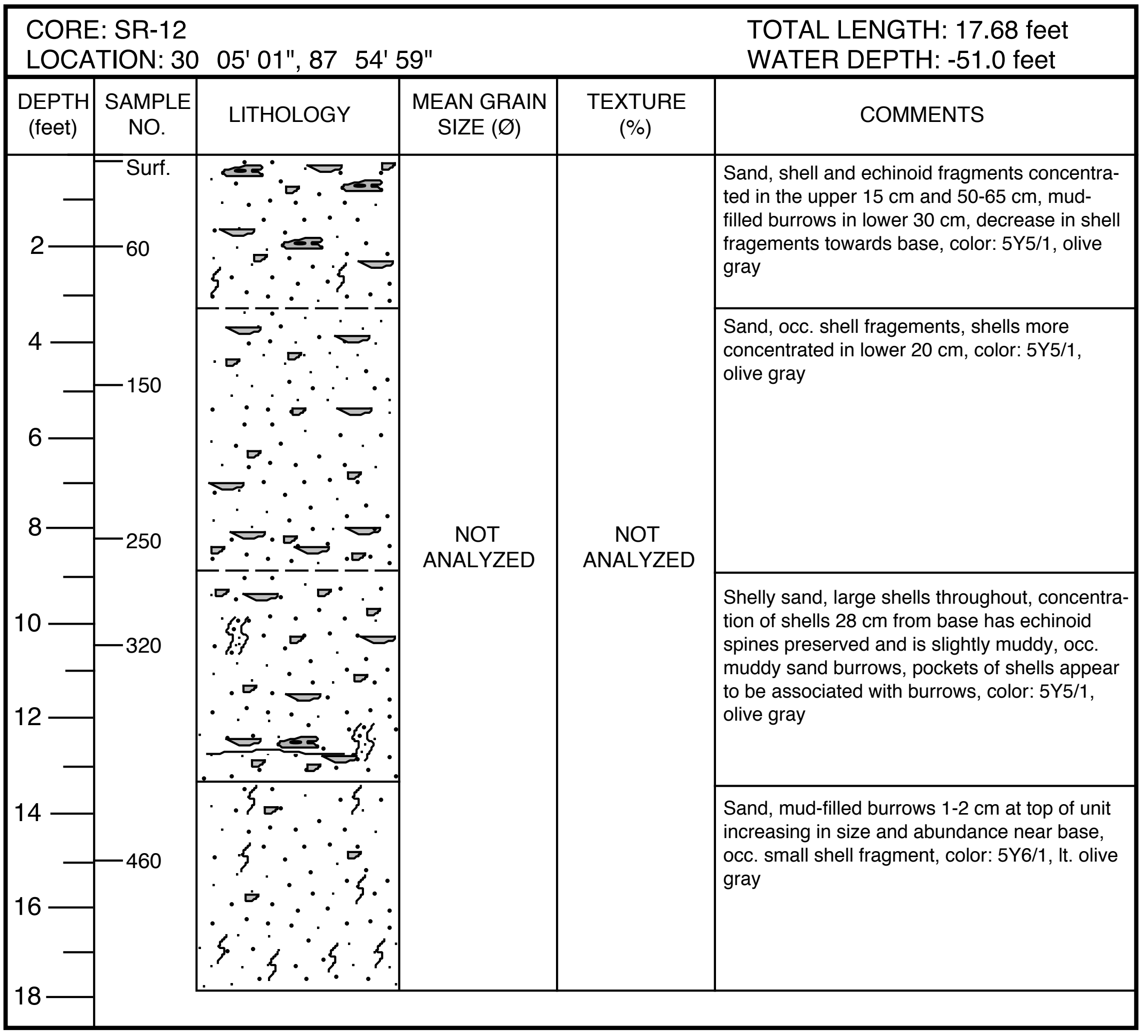
A-9.--Columnar section of EEZ vibracore SR-9 (modified from Parker and others, 1997).



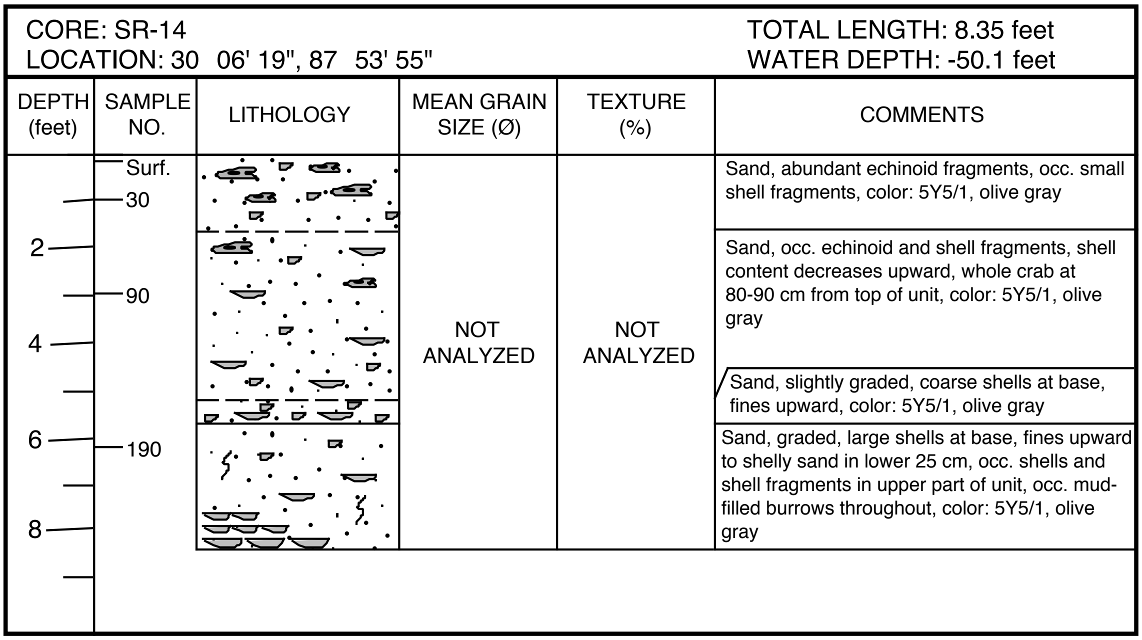
A-10.--Columnar section of EEZ vibracore SR-10 (modified from Parker and others, 1997).



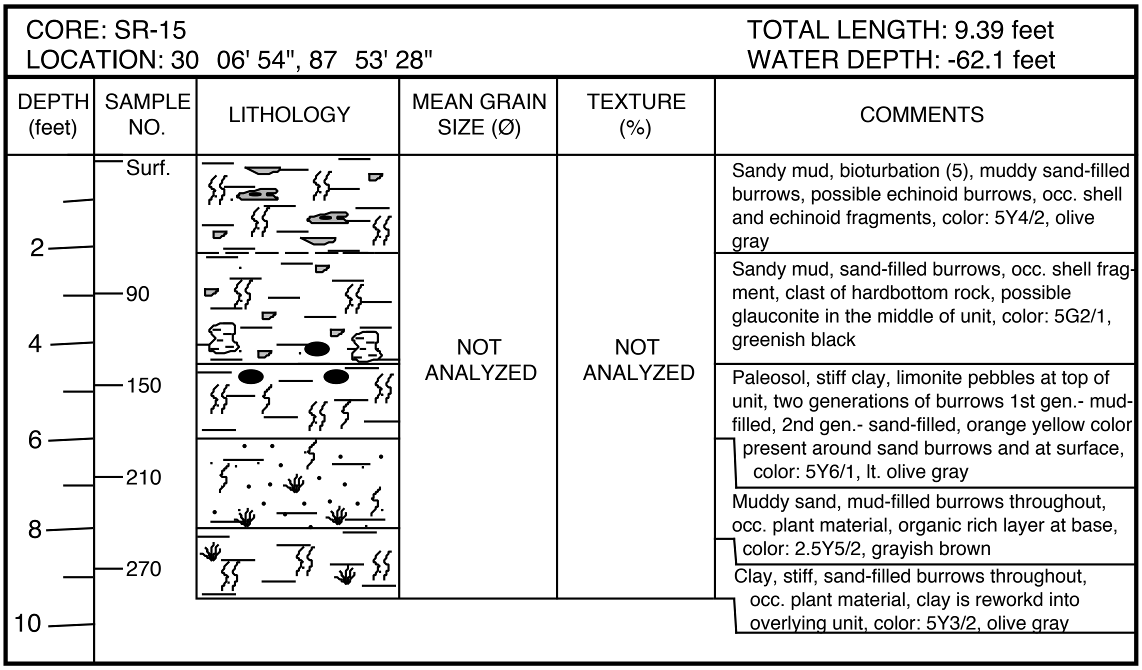
A-11.--Columnar section of EEZ vibracore SR-11 (modified from Parker and others, 1997).



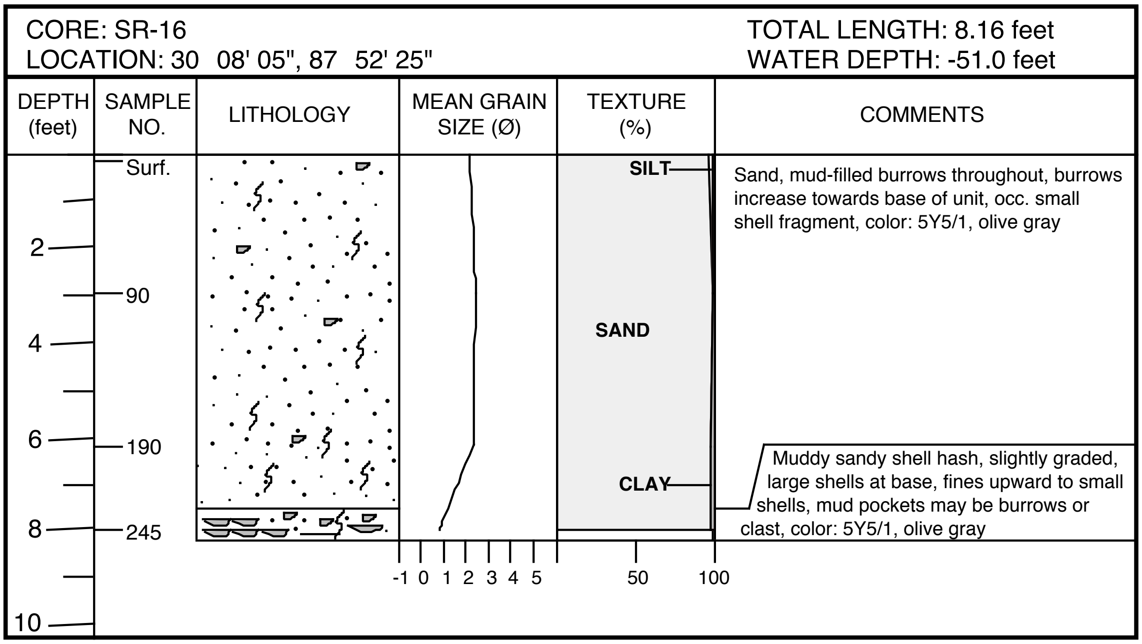
A-12.--Columnar section of EEZ vibracore SR-12 (modified from Parker and others, 1997).



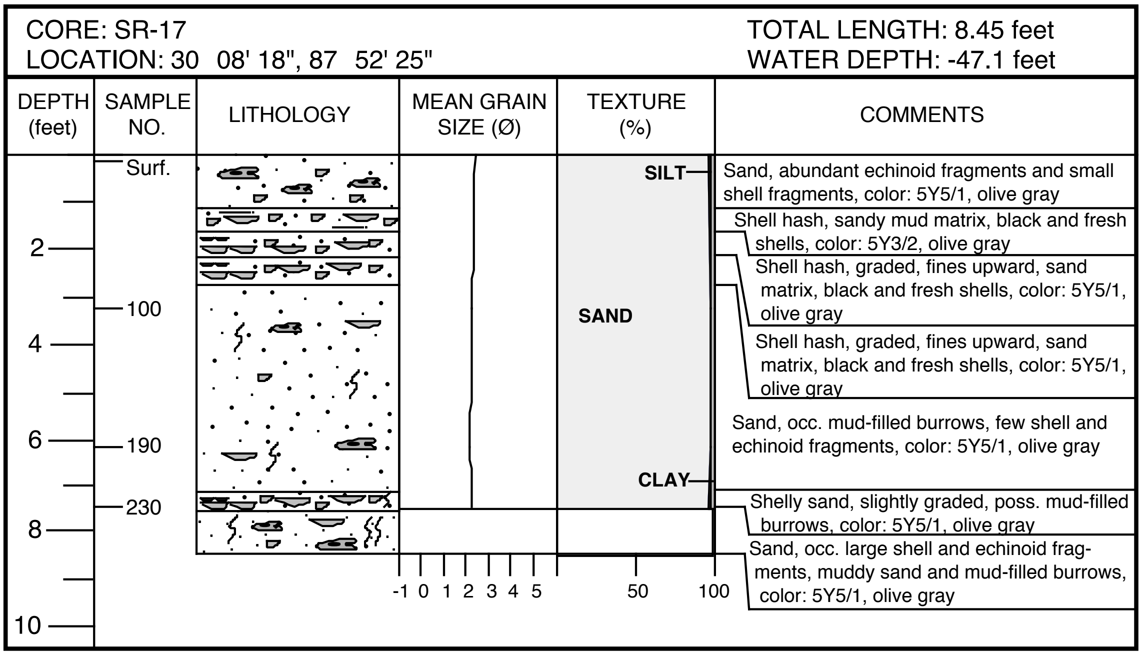
A-13.--Columnar section of EEZ vibracore SR-14 (modified from Parker and others, 1997).



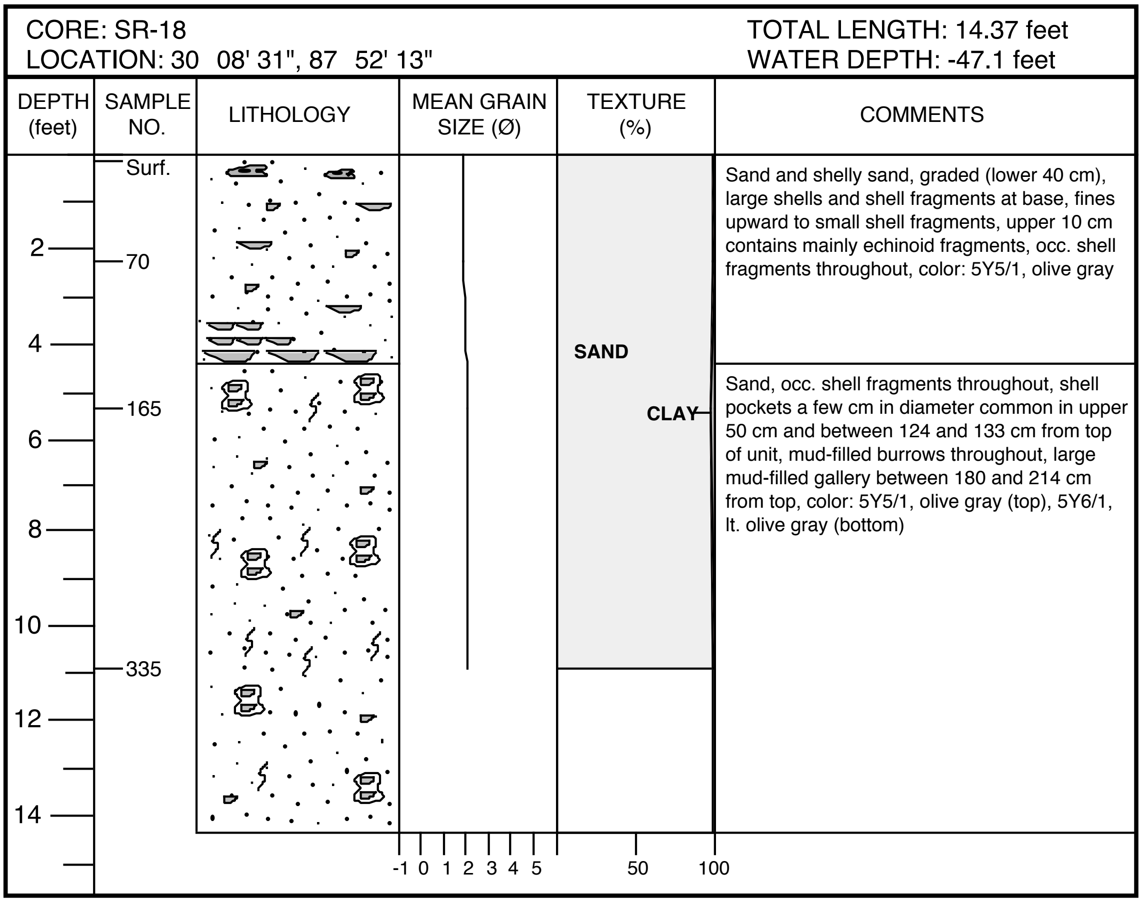
A-14.--Columnar section of EEZ vibracore SR-15 (modified from Parker and others, 1997).



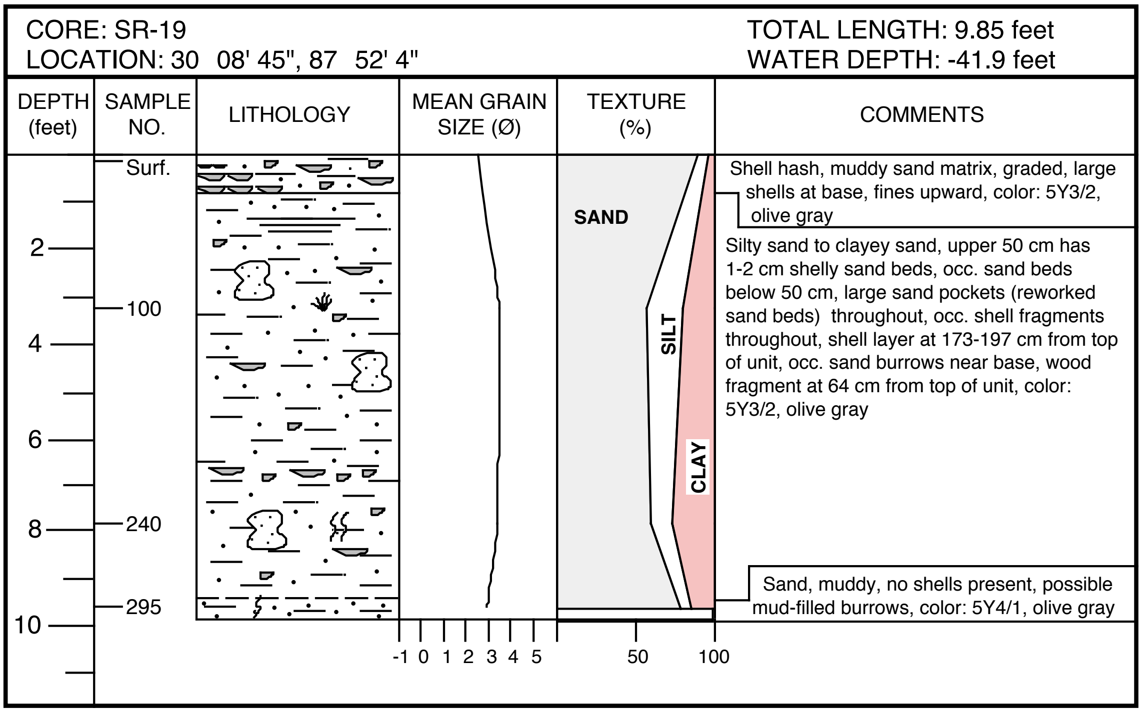
A-15.--Columnar section of EEZ vibracore SR-16 (modified from Parker and others, 1997).



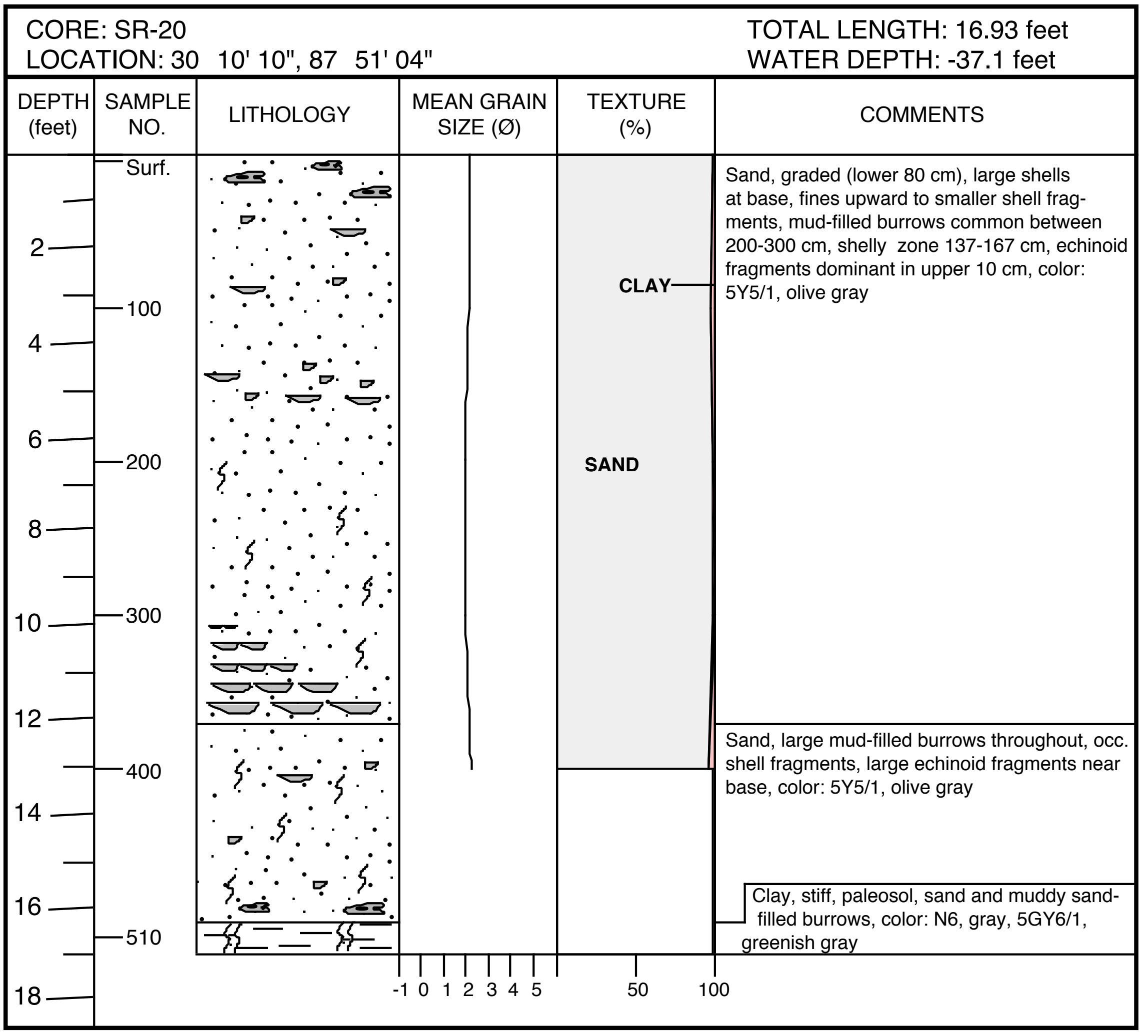
A-16.--Columnar section of EEZ vibracore SR-17 (modified from Parker and others, 1997).



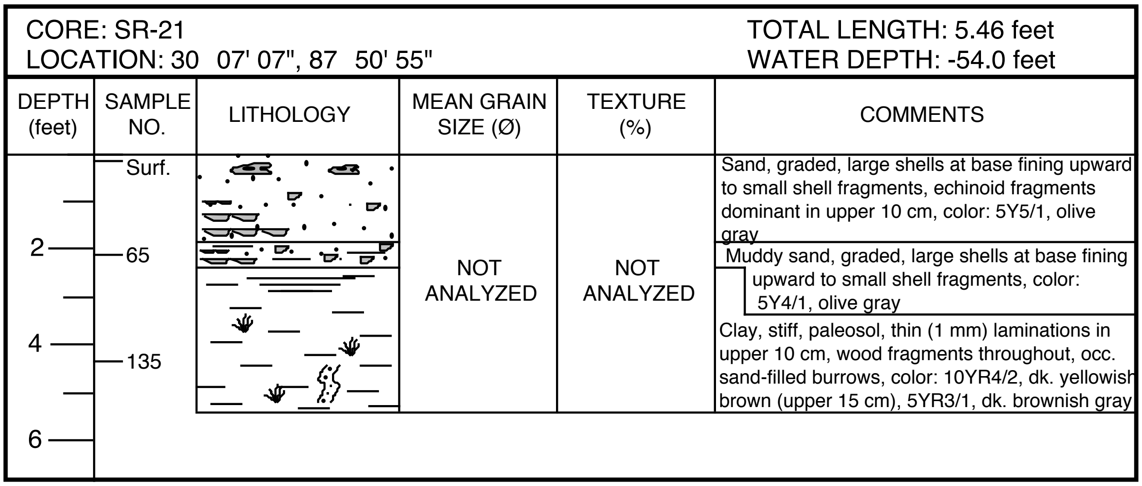
A-17.--Columnar section of EEZ vibracore SR-18 (modified from Parker and others, 1997).



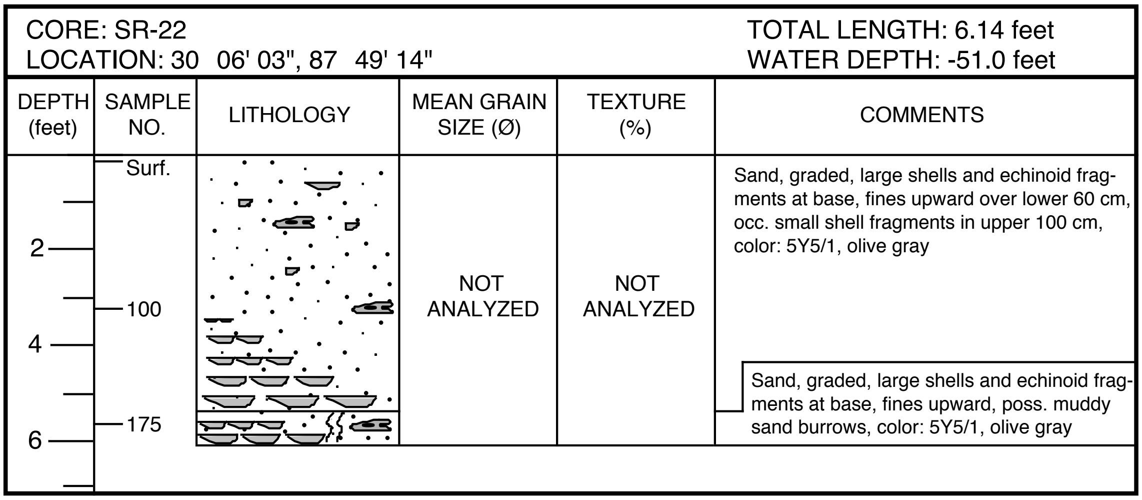
A-18.--Columnar section of EEZ vibracore SR-19 (modified from Parker and others, 1997).



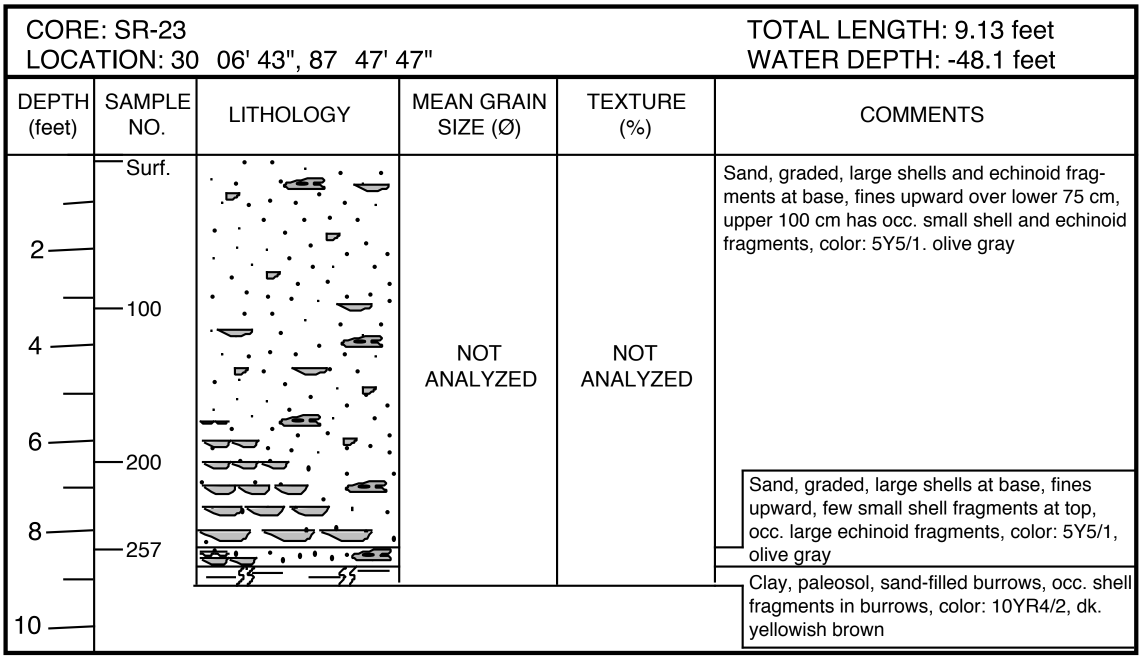
A-19.--Columnar section of EEZ vibracore SR-20 (modified from Parker and others, 1997).



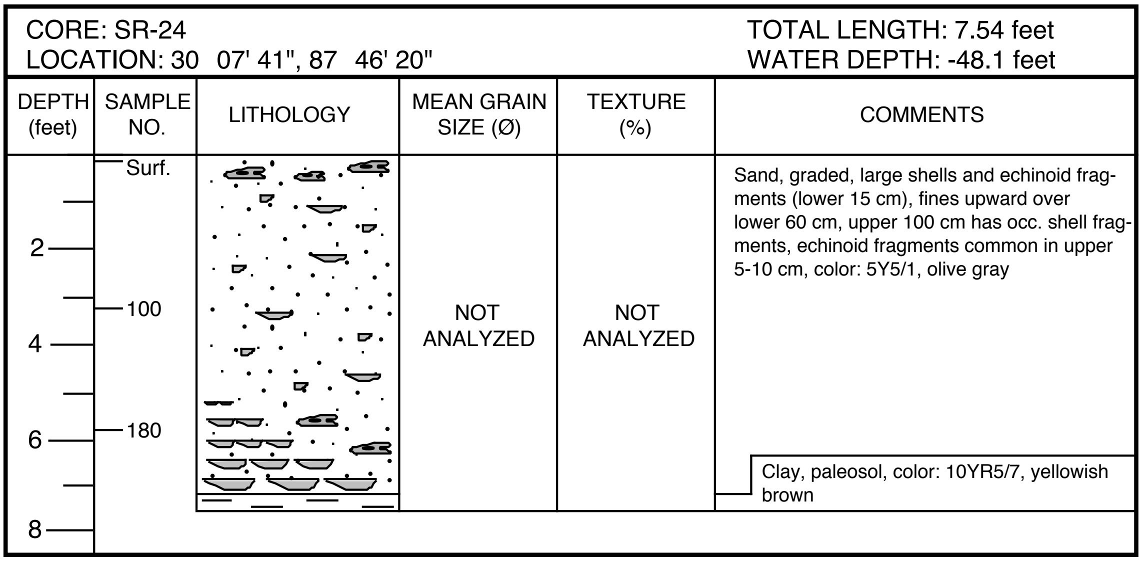
A-20.--Columnar section of EEZ vibracore SR-21 (modified from Parker and others, 1997).



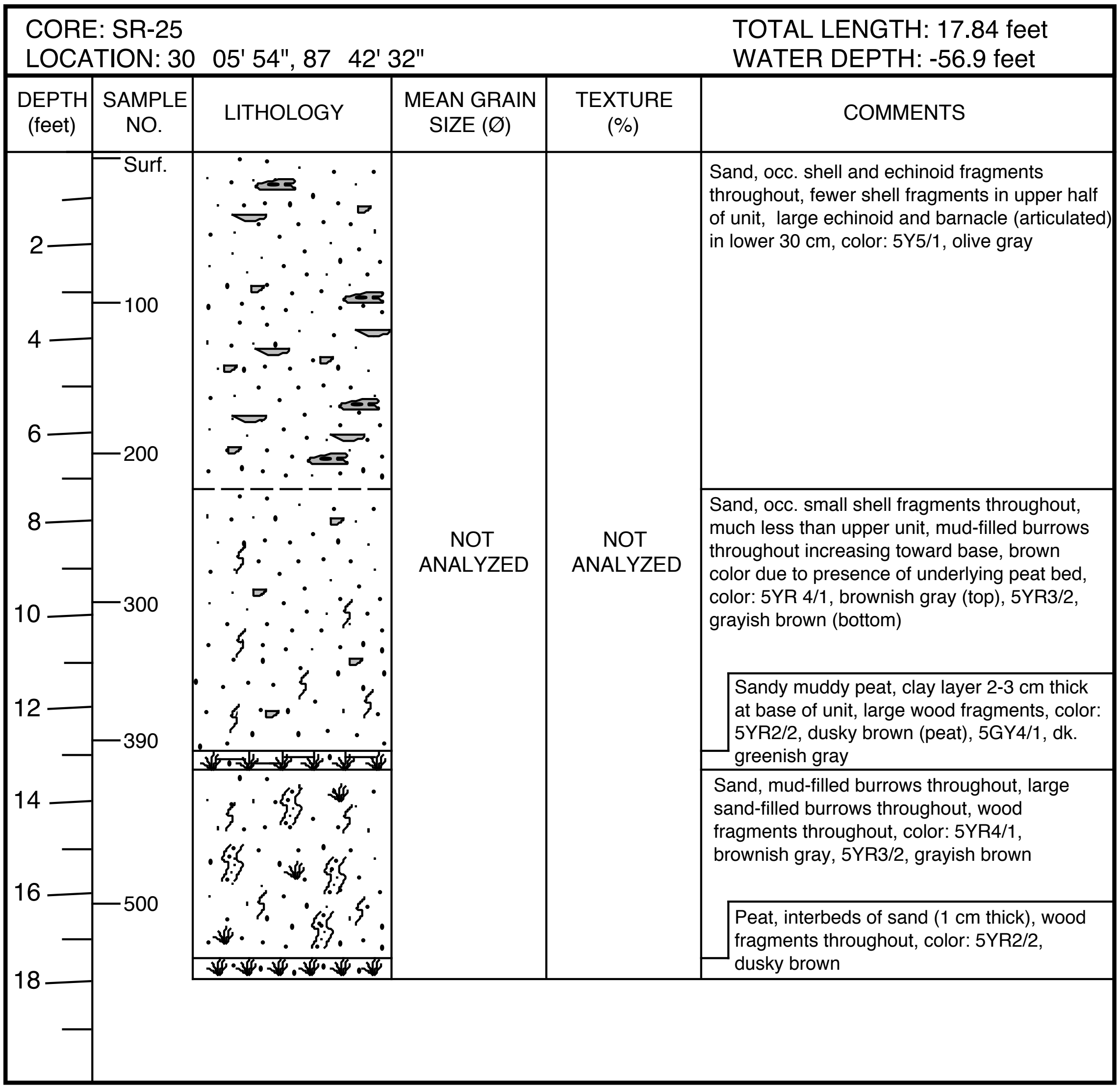
A-21.--Columnar section of EEZ vibracore SR-22 (modified from Parker and others, 1997).



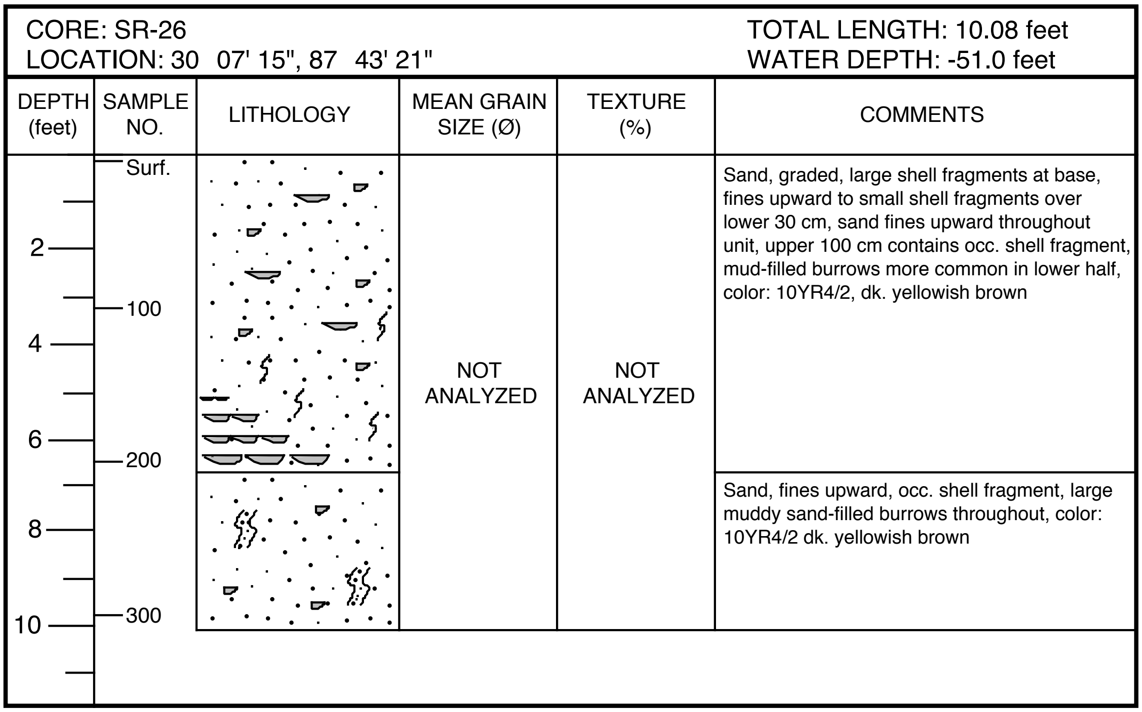
A-22.--Columnar section of EEZ vibracore SR-23 (modified from Parker and others, 1997).



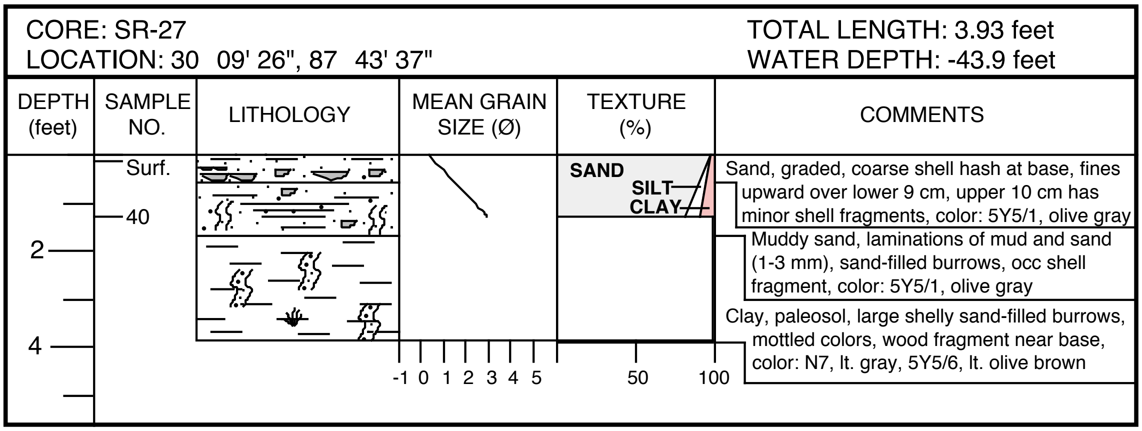
A-23.--Columnar section of EEZ vibracore SR-24 (modified from Parker and others, 1997).



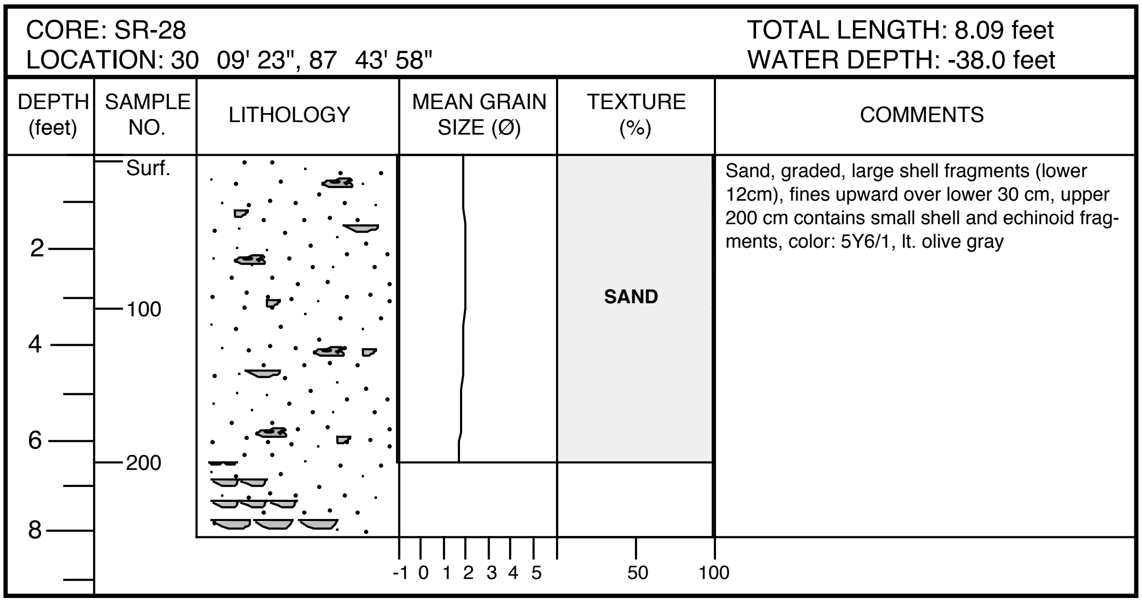
A-24.--Columnar section of EEZ vibracore SR-25 (modified from Parker and others, 1997).



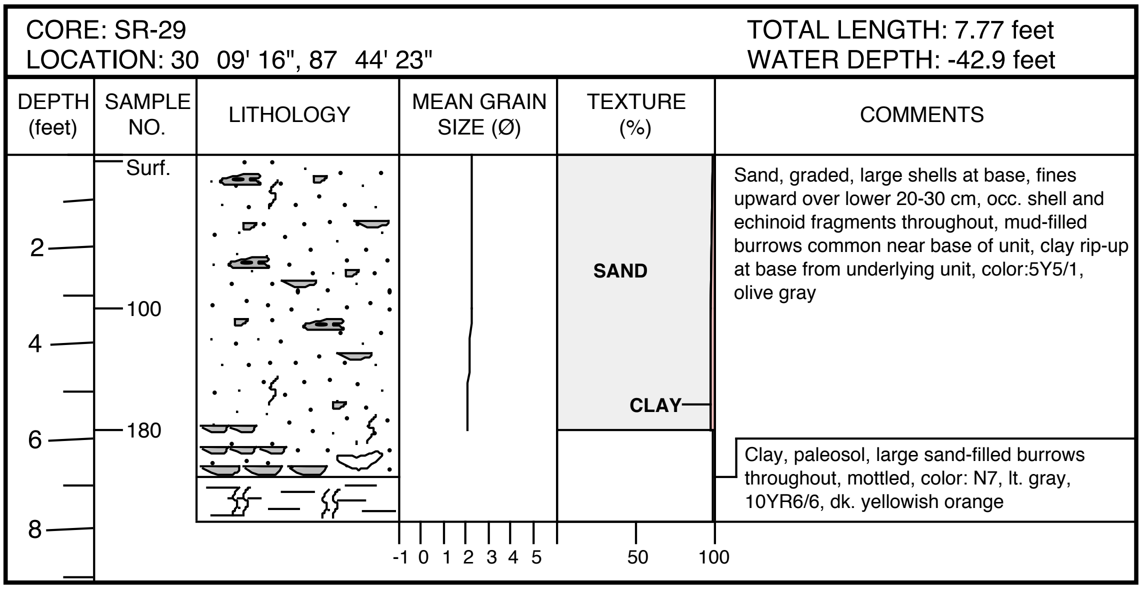
A-25.--Columnar section of EEZ vibracore SR-26 (modified from Parker and others, 1997).



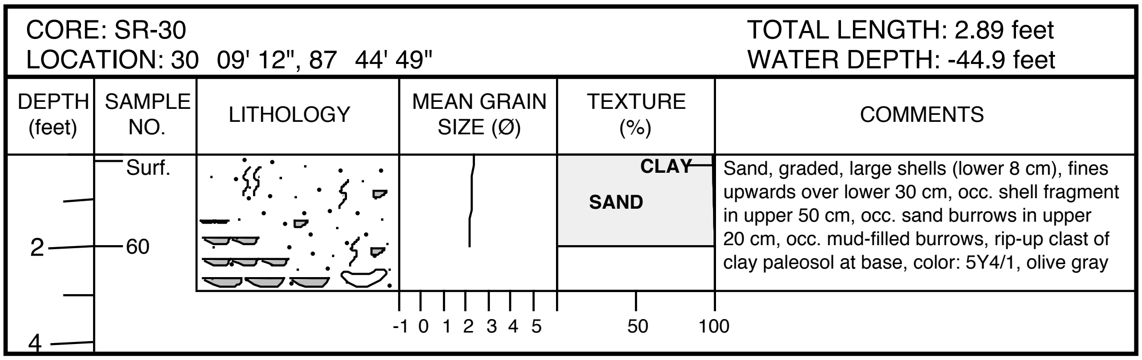
A-26.--Columnar section of EEZ vibracore SR-27 (modified from Parker and others, 1997).



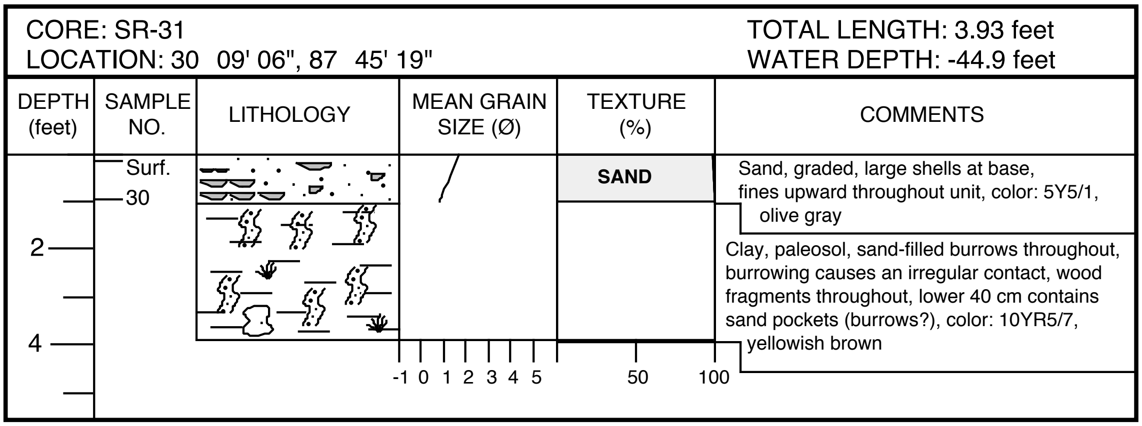
A-27.--Columnar section of EEZ vibracore SR-28 (modified from Parker and others, 1997).



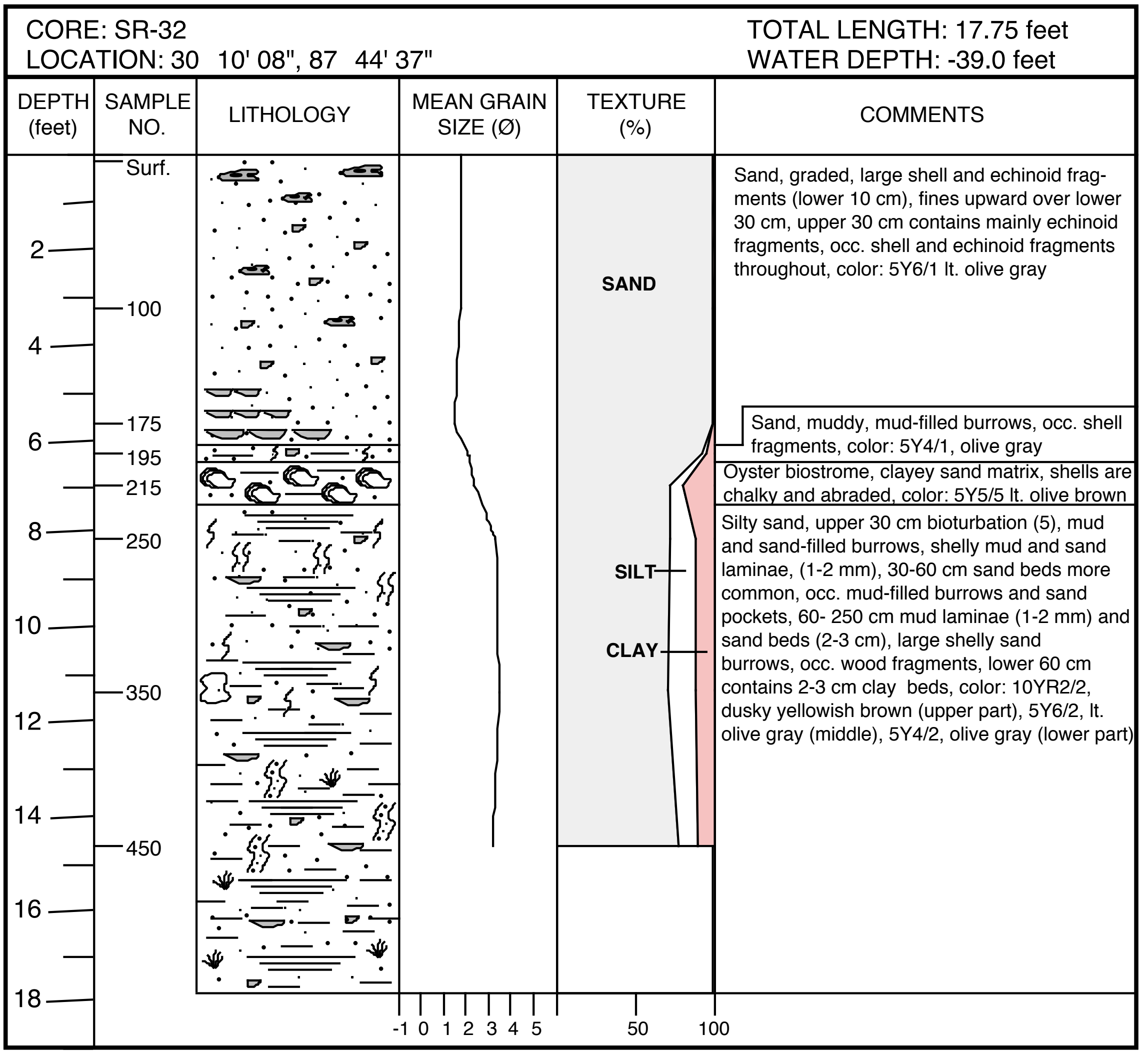
A-28.--Columnar section of EEZ vibracore SR-29 (modified from Parker and others, 1997).



A-29.--Columnar section of EEZ vibracore SR-30 (modified from Parker and others, 1997).

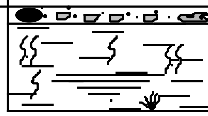


A-30.--Columnar section of EEZ vibracore SR-31 (modified from Parker and others, 1997).

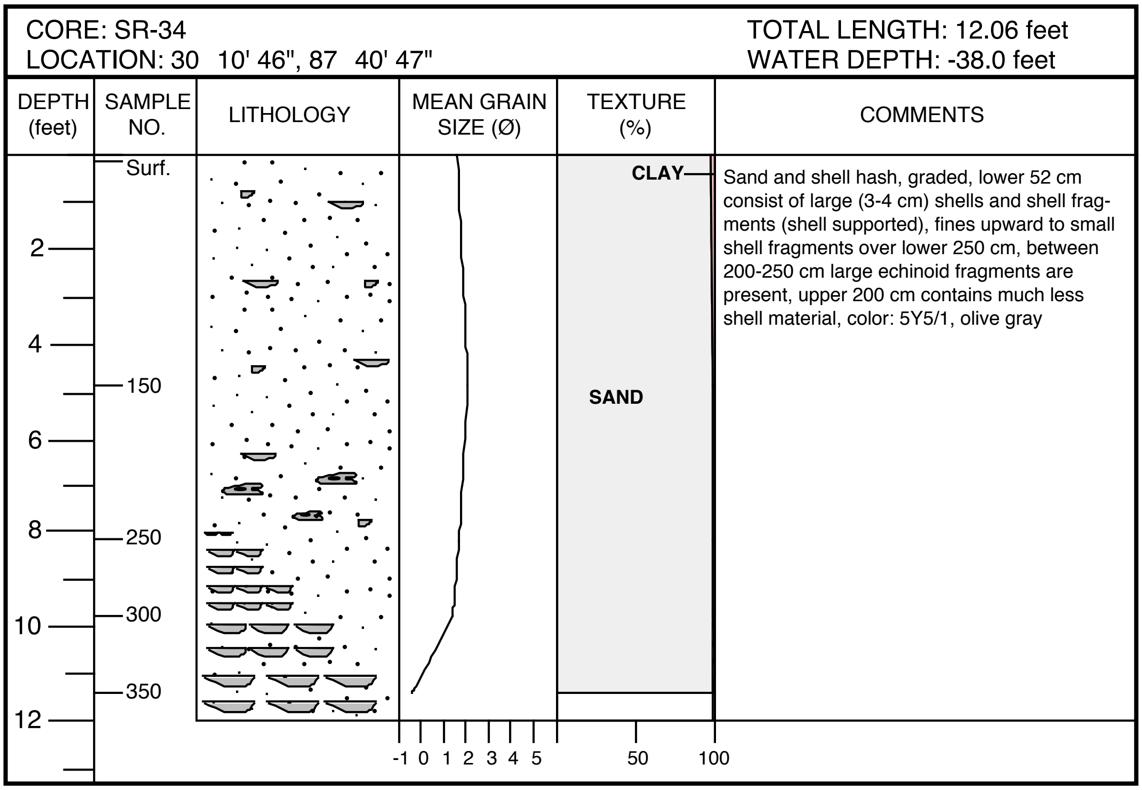


A-31.--Columnar section of EEZ vibracore SR-32 (modified from Parker and others, 1997).

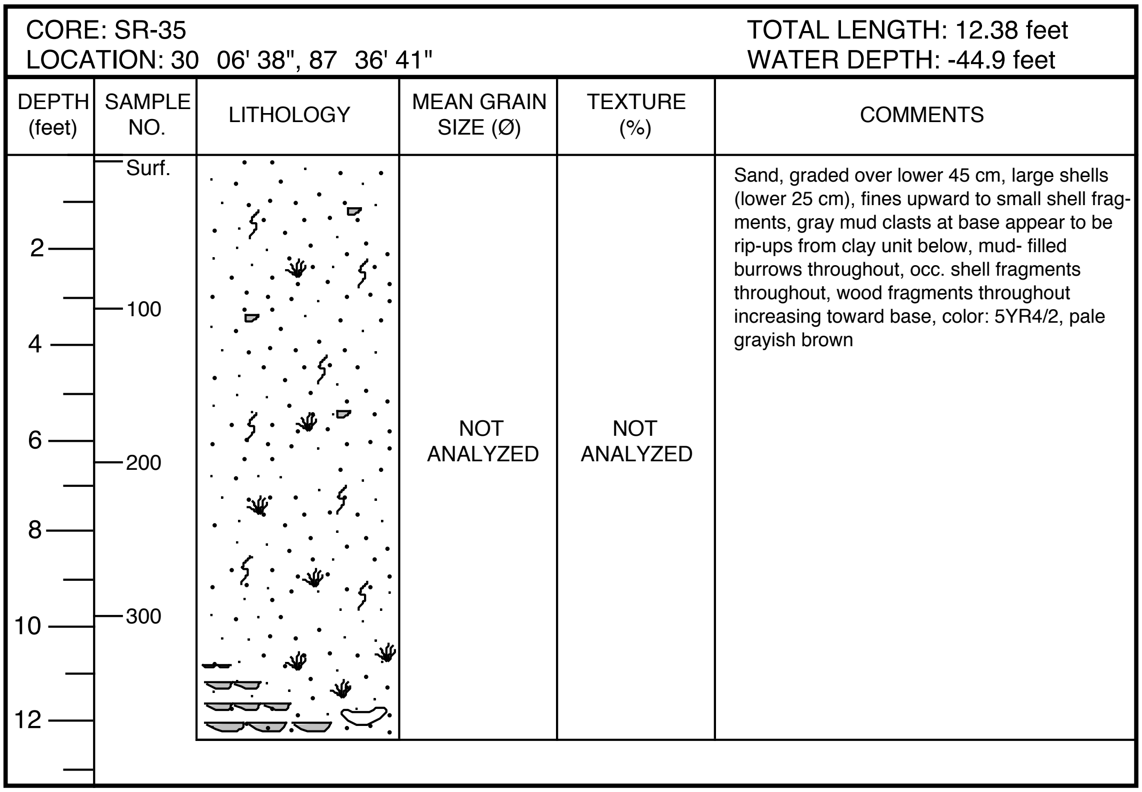
CORE: SR-33 | TOTAL LENGTH: 2.21 feet
LOCATION: 30 11' 05", 87 45' 07" | WATER DEPTH: -41.9 feet

DEPTH (feet)	SAMPLE NO.	LITHOLOGY	MEAN GRAIN SIZE (Ø)	TEXTURE (%)	COMMENTS
	Surf.		NOT ANALYZED	NOT ANALYZED	Sand, shell and echinoid fragments at base, large limonite nodule at 7 cm, color: 5Y5/1, olive gray
2					Sandy clay, paleosol, sand and mud-filled burrows, sand-filled burrows are oxidized, thin sand beds, occ. wood fragments near base, color: 10YR5/7, yellowish brown

A-32.--Columnar section of EEZ vibracore SR-33 (modified from Parker and others, 1997).



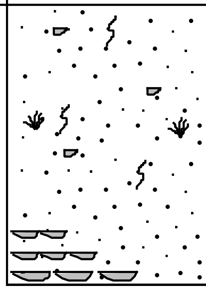
A-33.--Columnar section of EEZ vibracore SR-34 (modified from Parker and others, 1997).



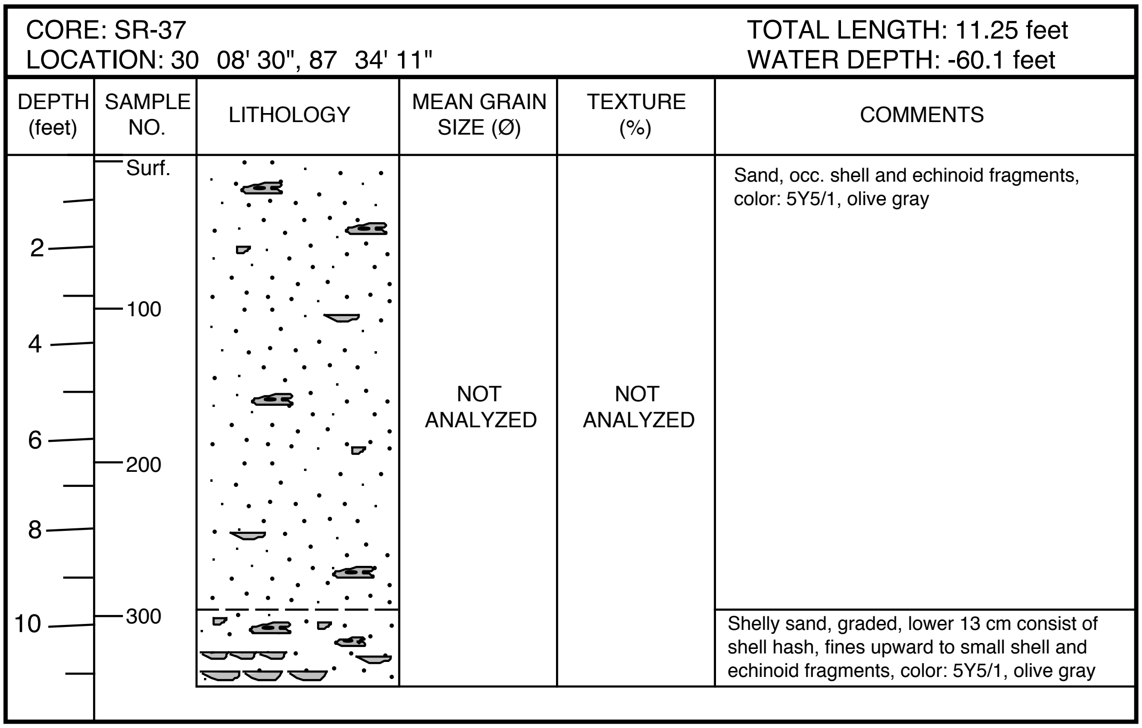
A-34.--Columnar section of EEZ vibracore SR-35 (modified from Parker and others, 1997).

CORE: SR-36
LOCATION: 30 06' 39", 87 36' 39"

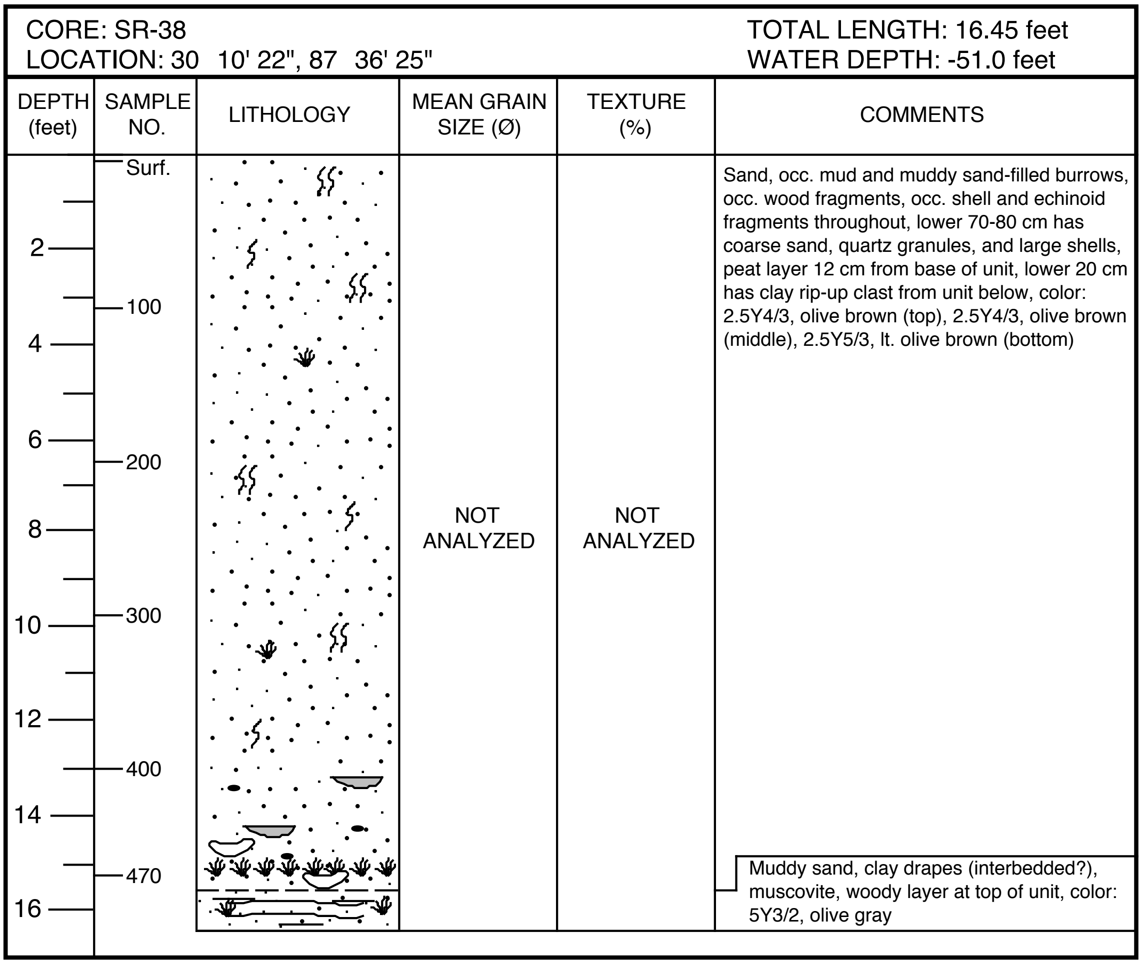
TOTAL LENGTH: 5.92 feet
WATER DEPTH: -75.1 feet

DEPTH (feet)	SAMPLE NO.	LITHOLOGY	MEAN GRAIN SIZE (Ø)	TEXTURE (%)	COMMENTS
2 4 6	Surf. 100		NOT ANALYZED	NOT ANALYZED	Sand, graded, large shells in lower 6 cm, fines upward over lower 24 cm to small shell fragments, occ. shell fragments throughout, occ. mud-filled burrows, wood fragments between 70-100 cm, color: 5Y5/1, olive gray

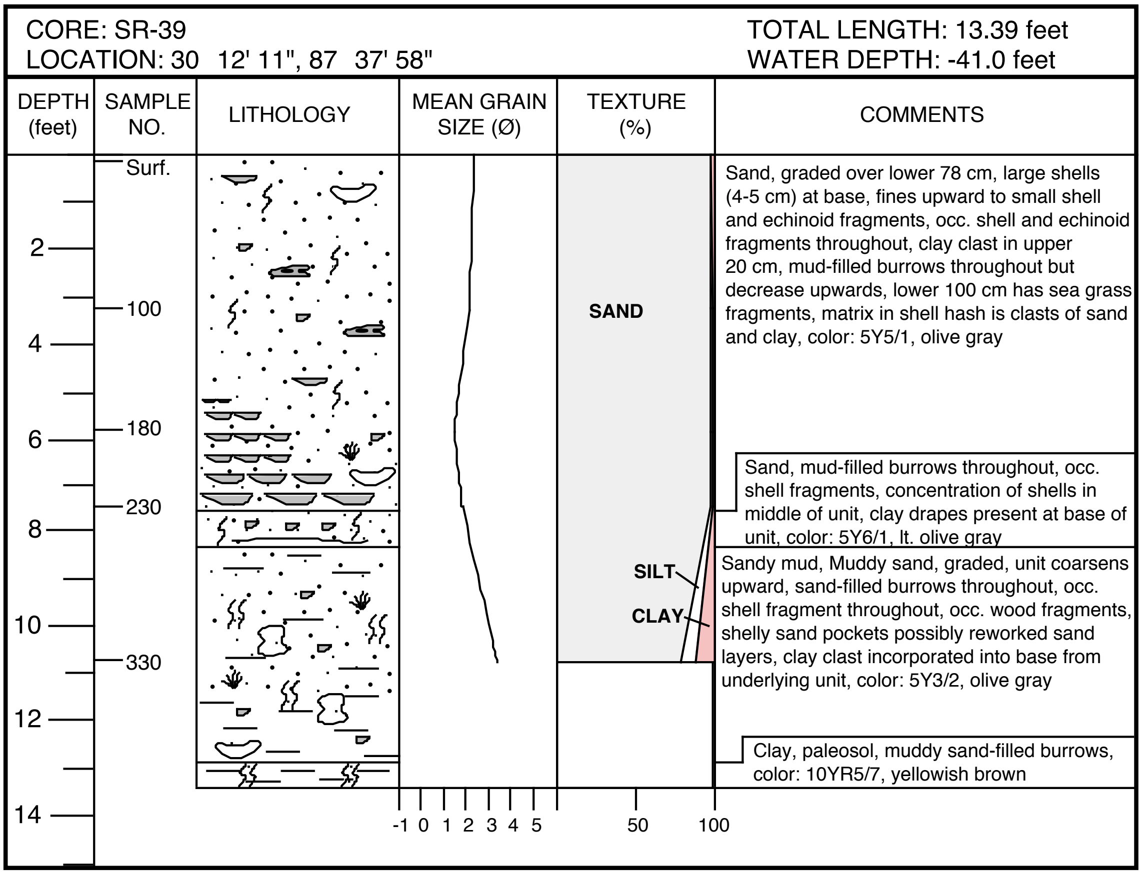
A-35.--Columnar section of EEZ vibracore SR-36 (modified from Parker and others, 1997).



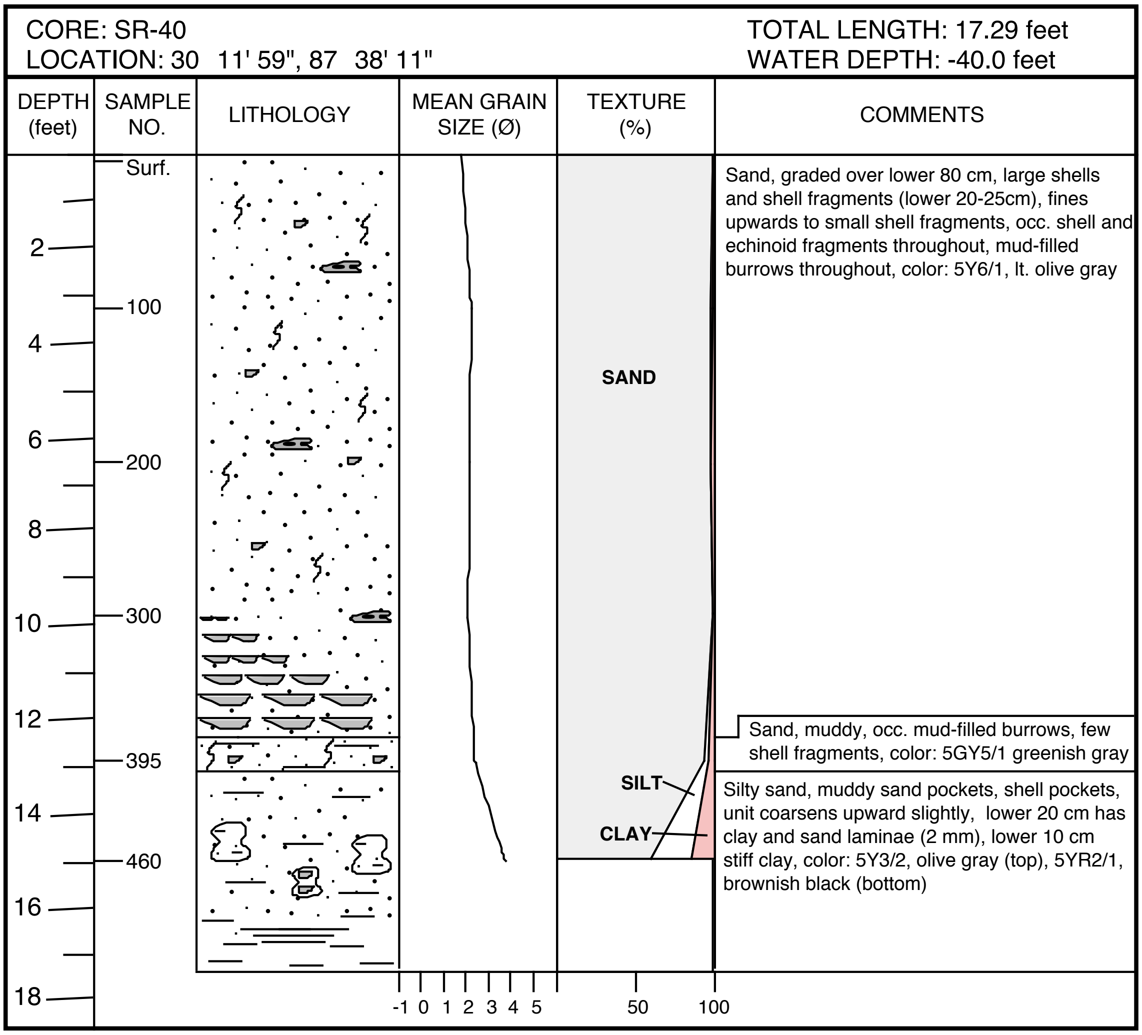
A-36.--Columnar section of EEZ vibracore SR-37 (modified from Parker and others, 1997).



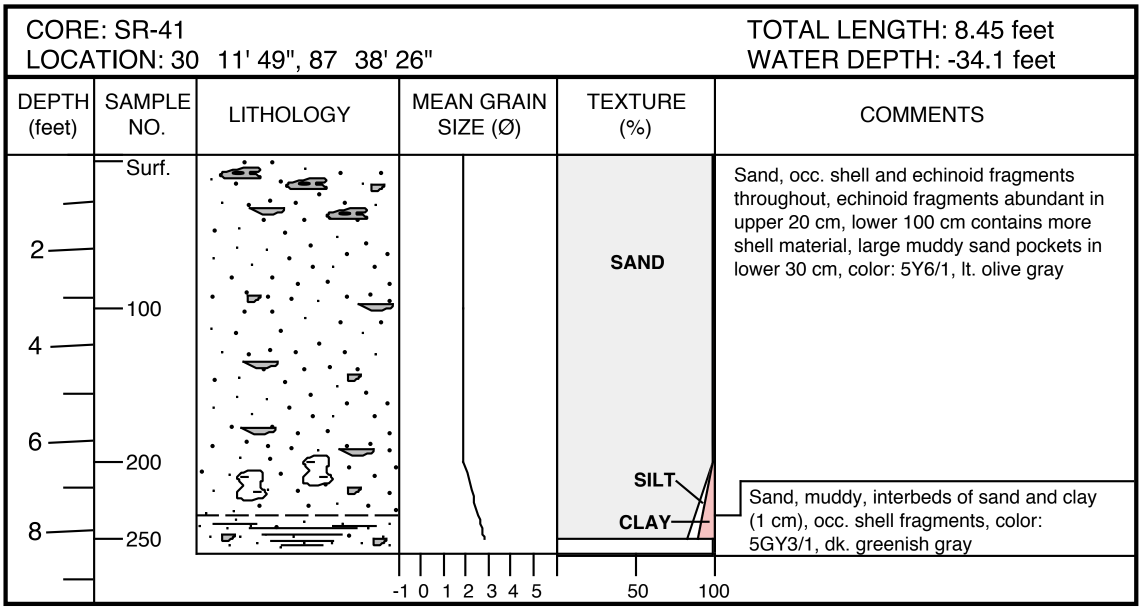
A-37.--Columnar section of EEZ vibracore SR-38 (modified from Parker and others, 1997).



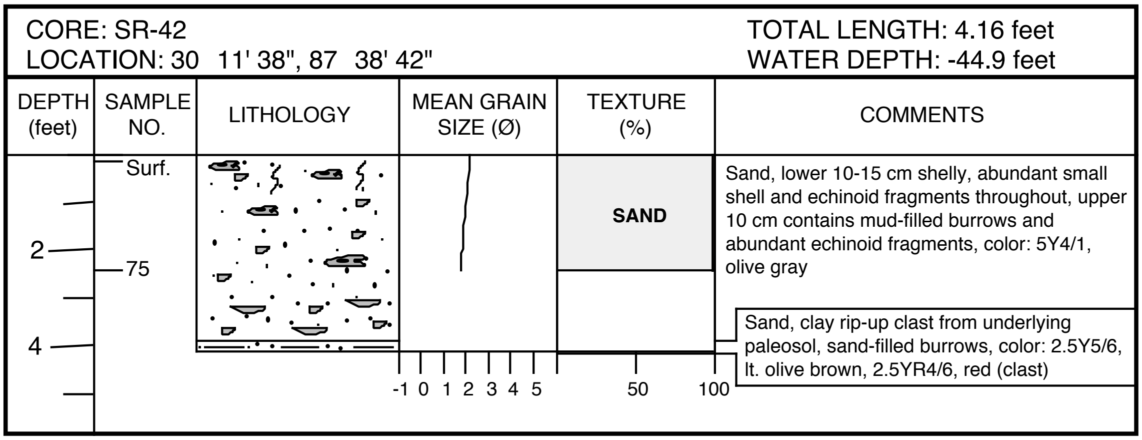
A-38.--Columnar section of EEZ vibracore SR-39 (modified from Parker and others, 1997).



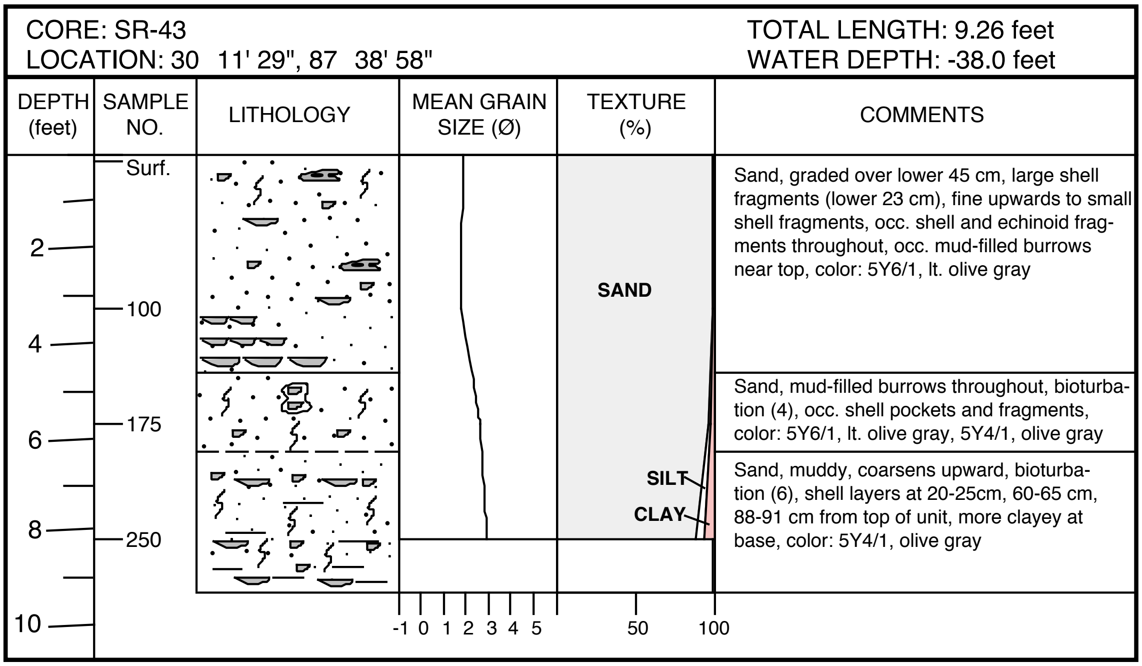
A-39.--Columnar section of EEZ vibracore SR-40 (modified from Parker and others, 1997).



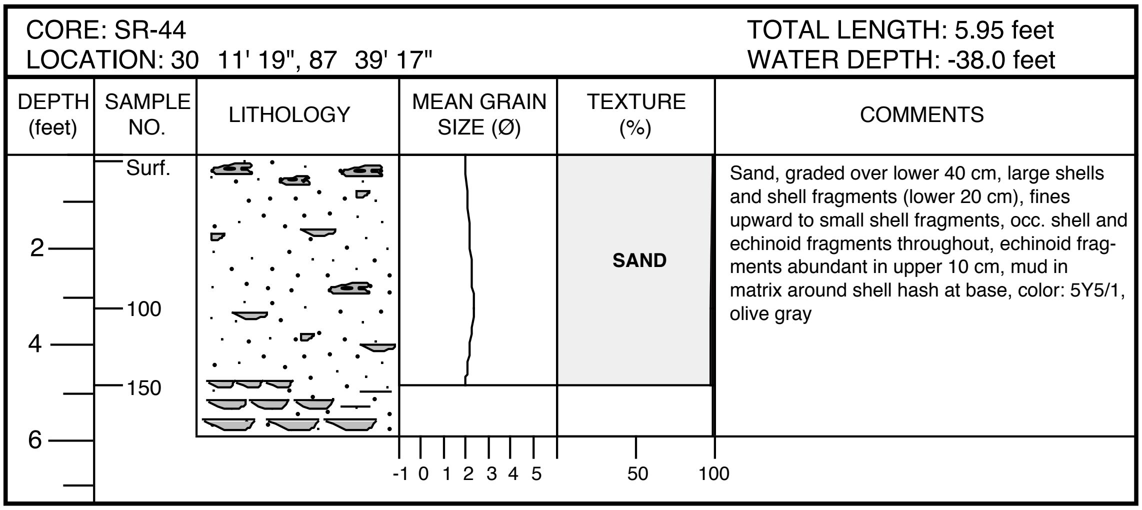
A-40.--Columnar section of EEZ vibracore SR-41 (modified from Parker and others, 1997).



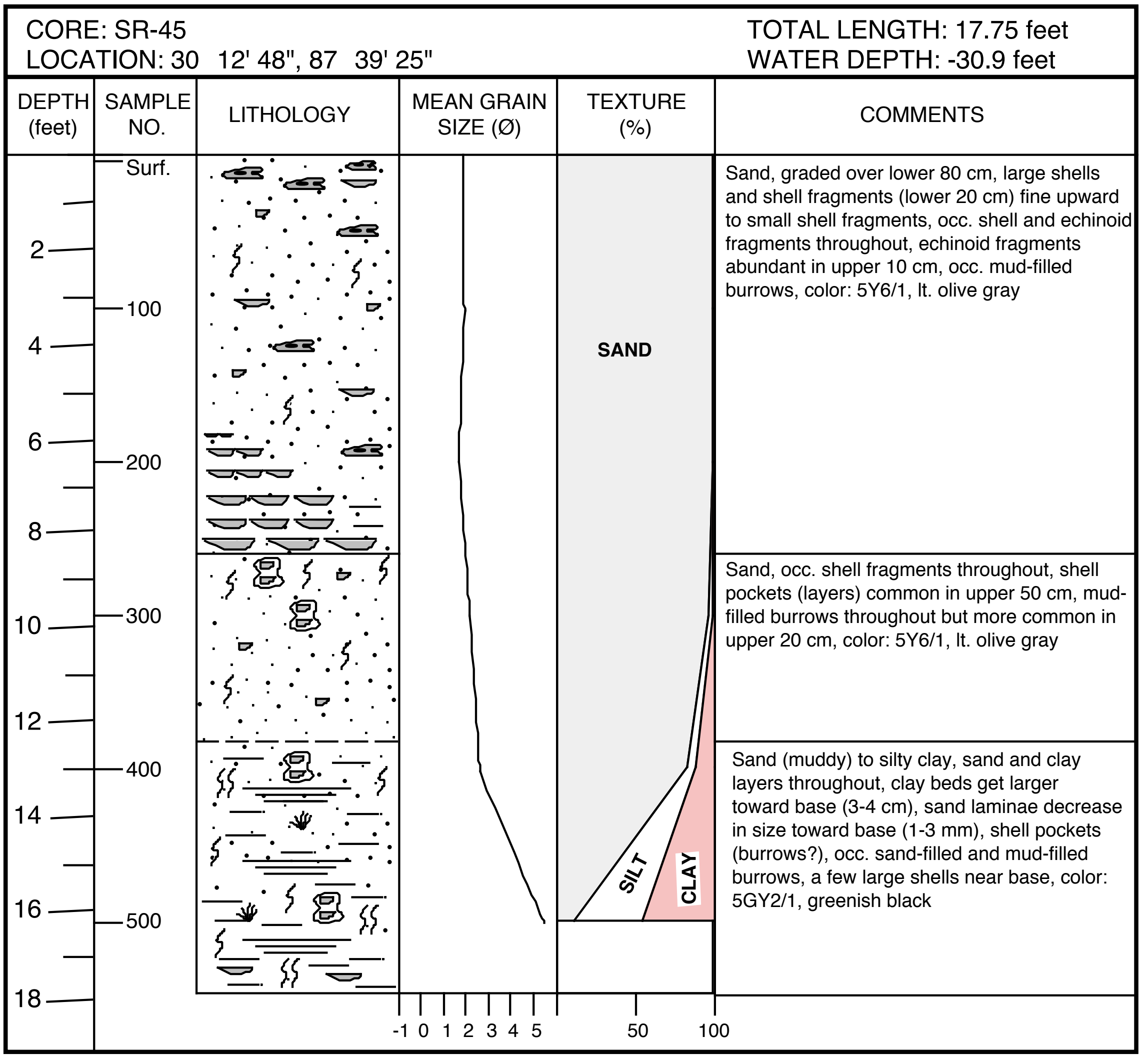
A-41.--Columnar section of EEZ vibracore SR-42 (modified from Parker and others, 1997).



A-42.--Columnar section of EEZ vibracore SR-43 (modified from Parker and others, 1997).



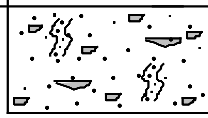
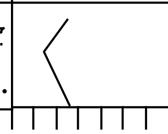
A-43.--Columnar section of EEZ vibracore SR-44 (modified from Parker and others, 1997).



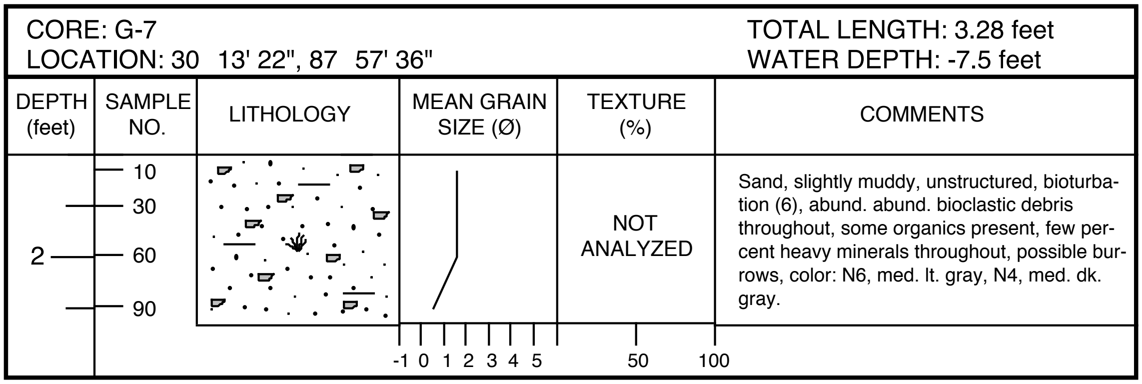
A-44.--Columnar section of EEZ vibracore SR-45 (modified from Parker and others, 1997).

CORE: G-6
LOCATION: 30 13' 10", 87 59' 43"

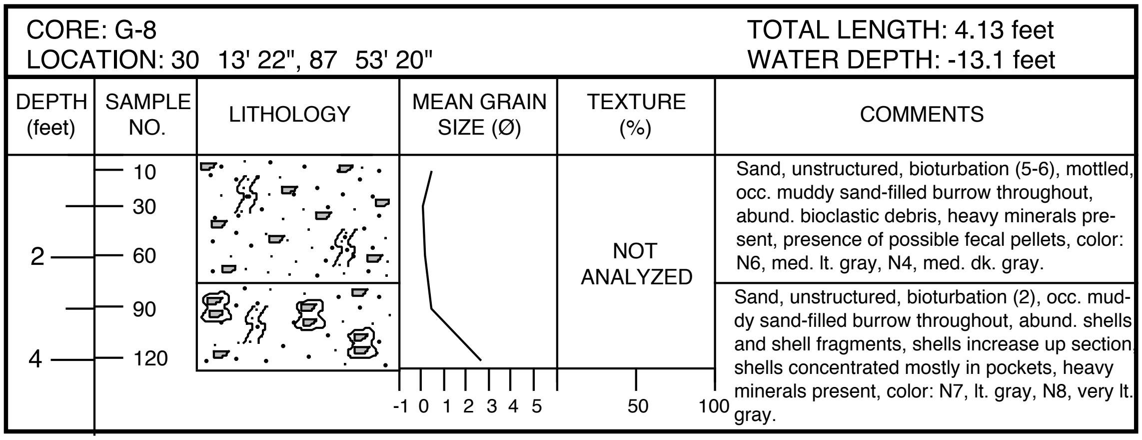
TOTAL LENGTH: 2.03 feet
WATER DEPTH: -10 feet

DEPTH (feet)	SAMPLE NO.	LITHOLOGY	MEAN GRAIN SIZE (Ø)	TEXTURE (%)	COMMENTS
2	10 30 60			NOT ANALYZED 50 100	Sand, unstructured, bioturbation (5), abund. bioclastic debris, abund. shells and shell fragments, heavy minerals present throughout, two horizons of muddy sand-filled burrows, color: N3, dk. gray, N5, med. gray, N7, lt. gray.

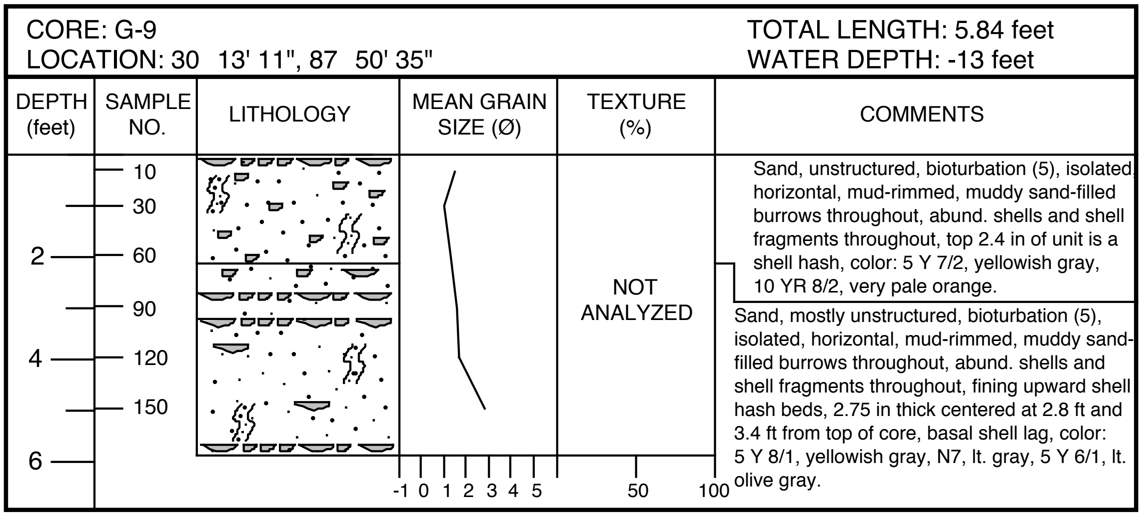
A-45.--Columnar section of EEZ vibracore G-6.



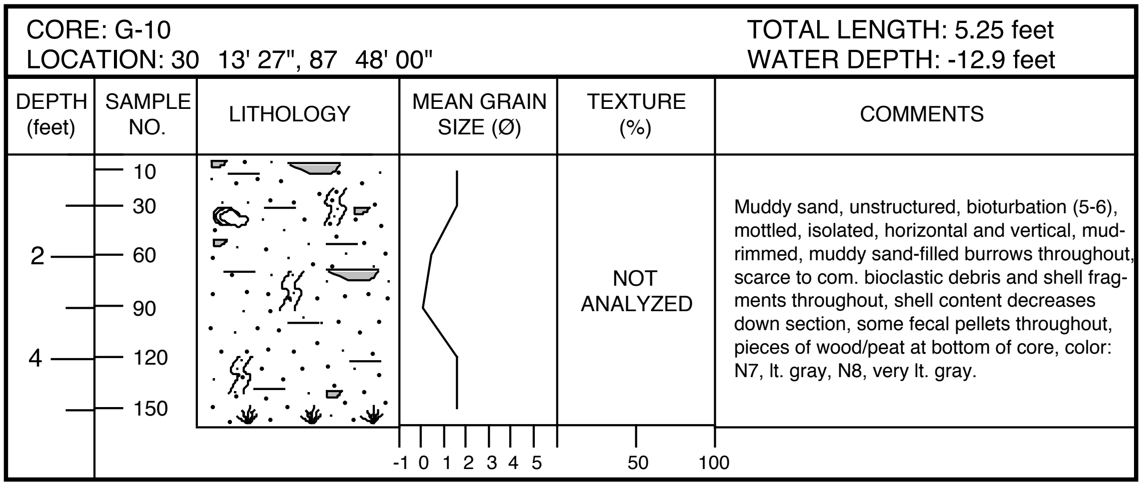
A-46.--Columnar section of EEZ vibracore G-7.



A-47.--Columnar section of EEZ vibracore G-8.



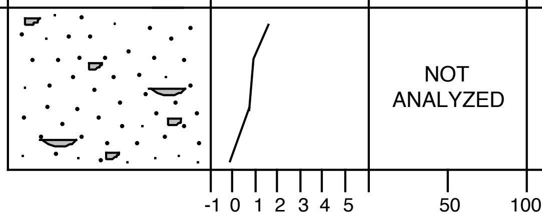
A-48.--Columnar section of EEZ vibracore G-9.



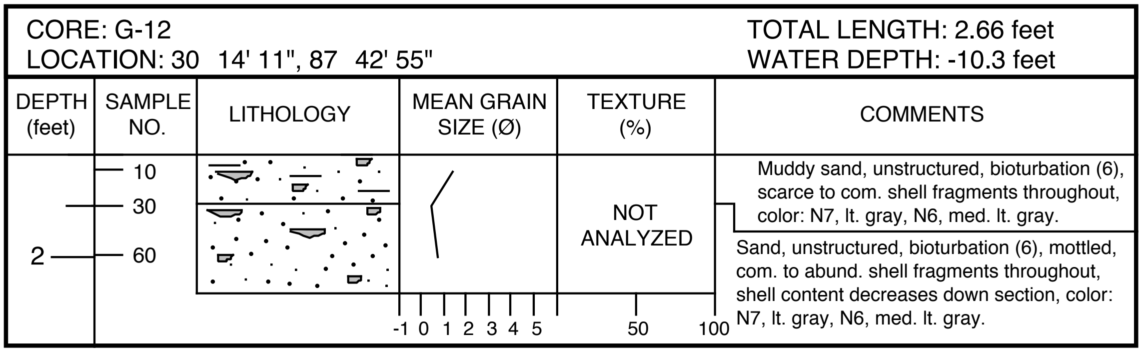
A-49.--Columnar section of EEZ vibracore G-10.

CORE: G-11 TOTAL LENGTH: 3.15 feet
LOCATION: 30 14' 05", 87 43' 52" WATER DEPTH: -7.4 feet

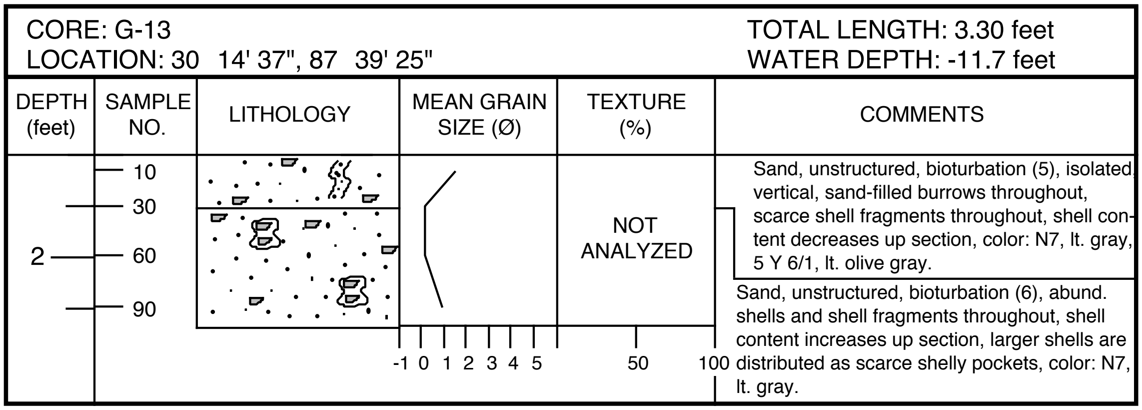
DEPTH (feet)	SAMPLE NO.	LITHOLOGY	MEAN GRAIN SIZE (Ø)	TEXTURE (%)	COMMENTS
	10				
	30			NOT ANALYZED	Sand, bioturbation (5-6), com. shells and shell fragments throughout, unit fines upward, shell content decreases upward, color: N6, med. lt. gray, N7, lt. gray.
2	60				
	90				



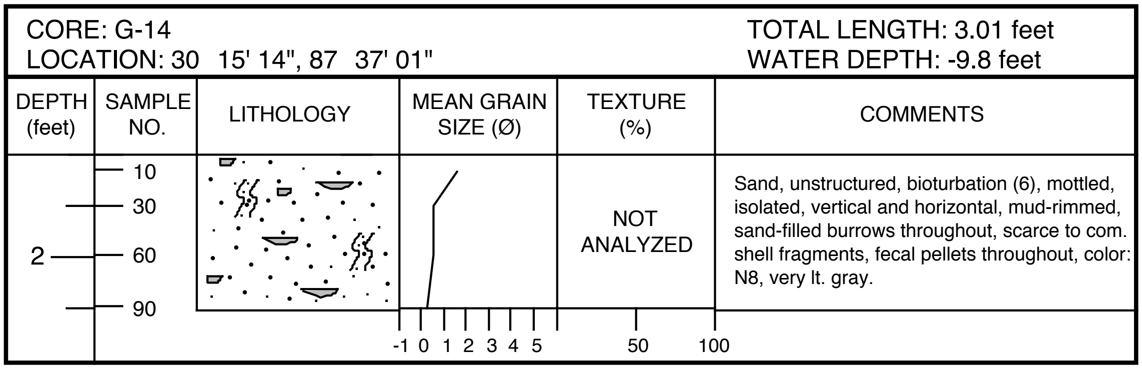
A-50.--Columnar section of EEZ vibracore G-11.



A-51.--Columnar section of EEZ vibracore G-12.



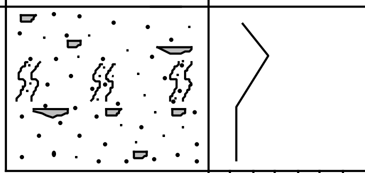
A-52.--Columnar section of EEZ vibracore G-13.



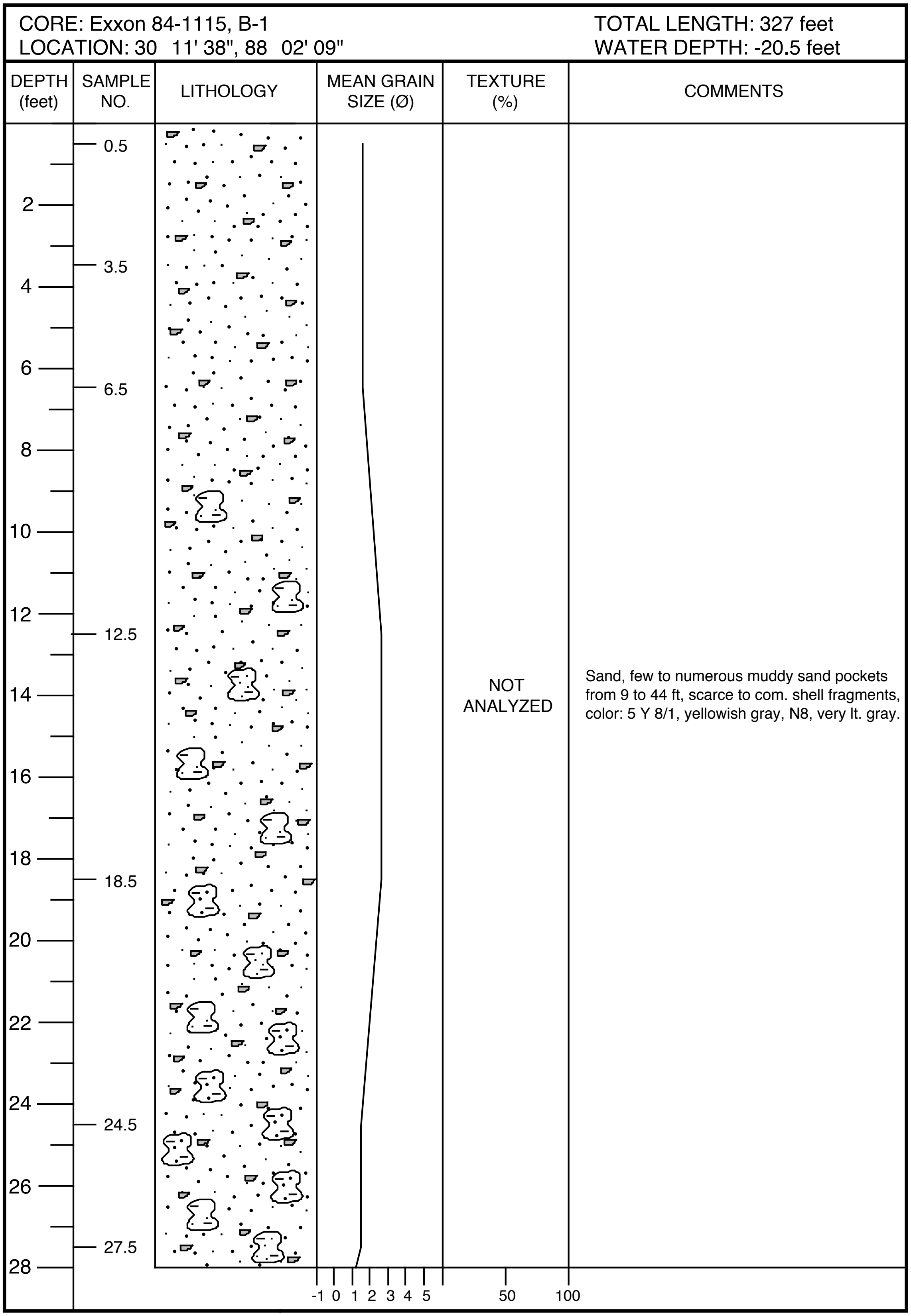
A-53.--Columnar section of EEZ vibracore G-14.

CORE: G-15
LOCATION: 30   15' 53", 87   34' 08"

TOTAL LENGTH: 3.18 feet
WATER DEPTH: -11.4 feet

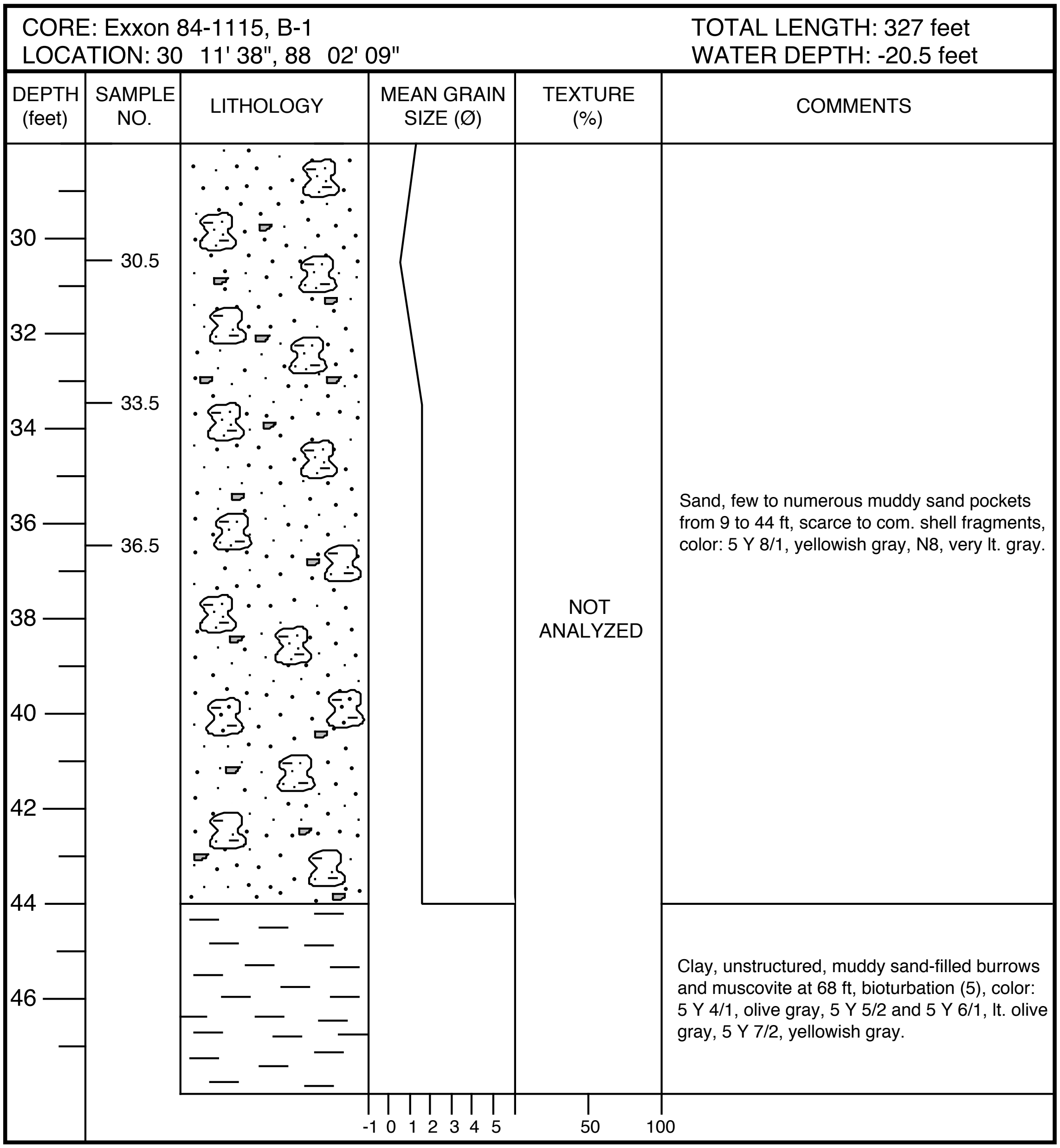
DEPTH (feet)	SAMPLE NO.	LITHOLOGY	MEAN GRAIN SIZE (Ø)	TEXTURE (%)	COMMENTS
2	10 30 60 90			NOT ANALYZED	Sand, unstructured, bioturbation (5), mottled, horizontal, mud-rimmed, sand-filled burrows com. between 1 ft and 2 ft from top of core, sand fines upward, scarce to com. shells throughout, shell content decreases up section and down section from middle of unit, heavy minerals present throughout, com. fecal pellets throughout, color: N8, very lt. gray, 10 YR 4/2, dk. yellowish brown.
			-1 0 1 2 3 4 5	50 100	

A-54.--Columnar section of EEZ vibracore G-15.

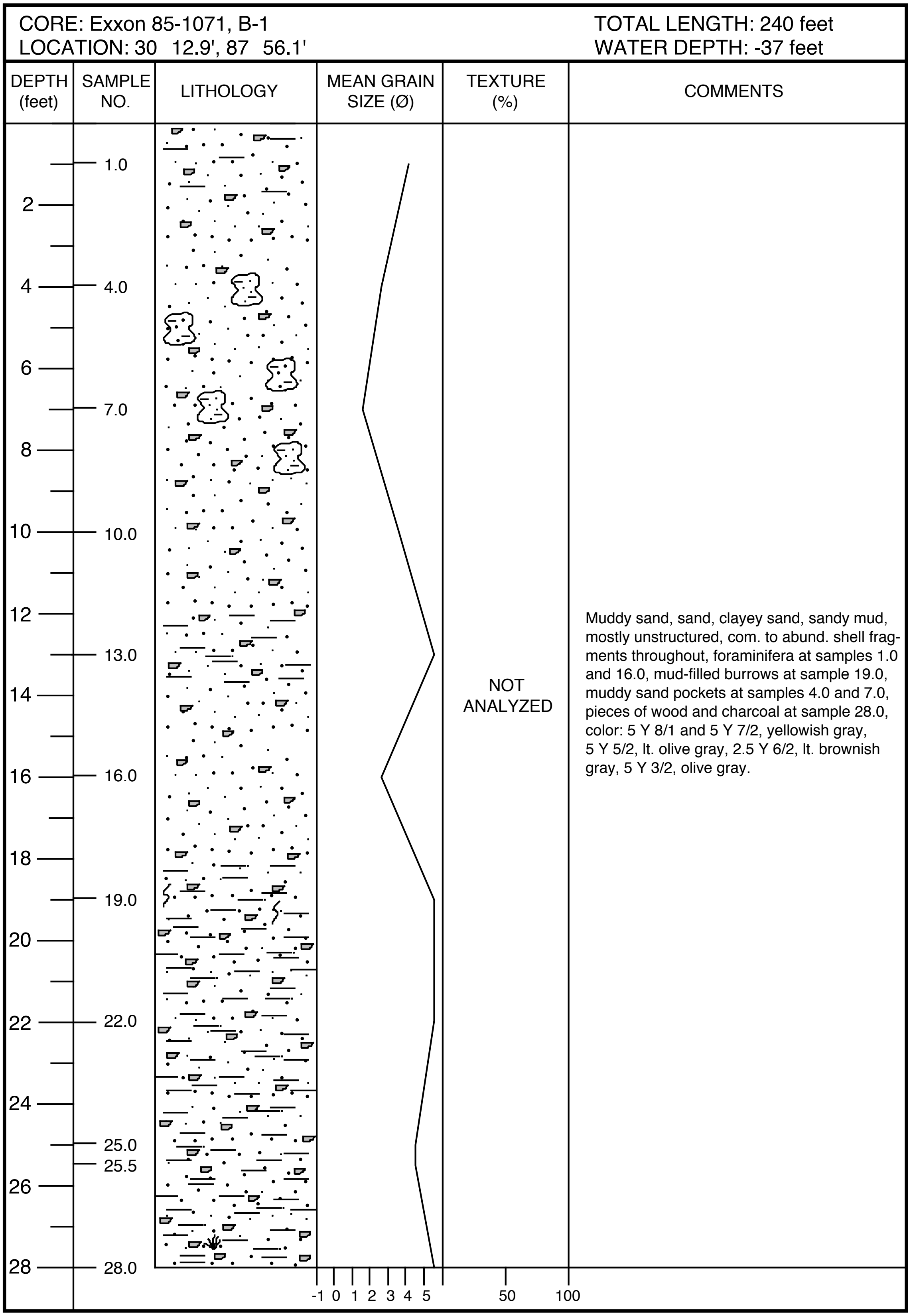


A-55.--Columnar section of EEZ boring Exxon 84-1115, B-1 (modified from Hummell, 1996).

CONTINUED FROM PREVIOUS PAGE

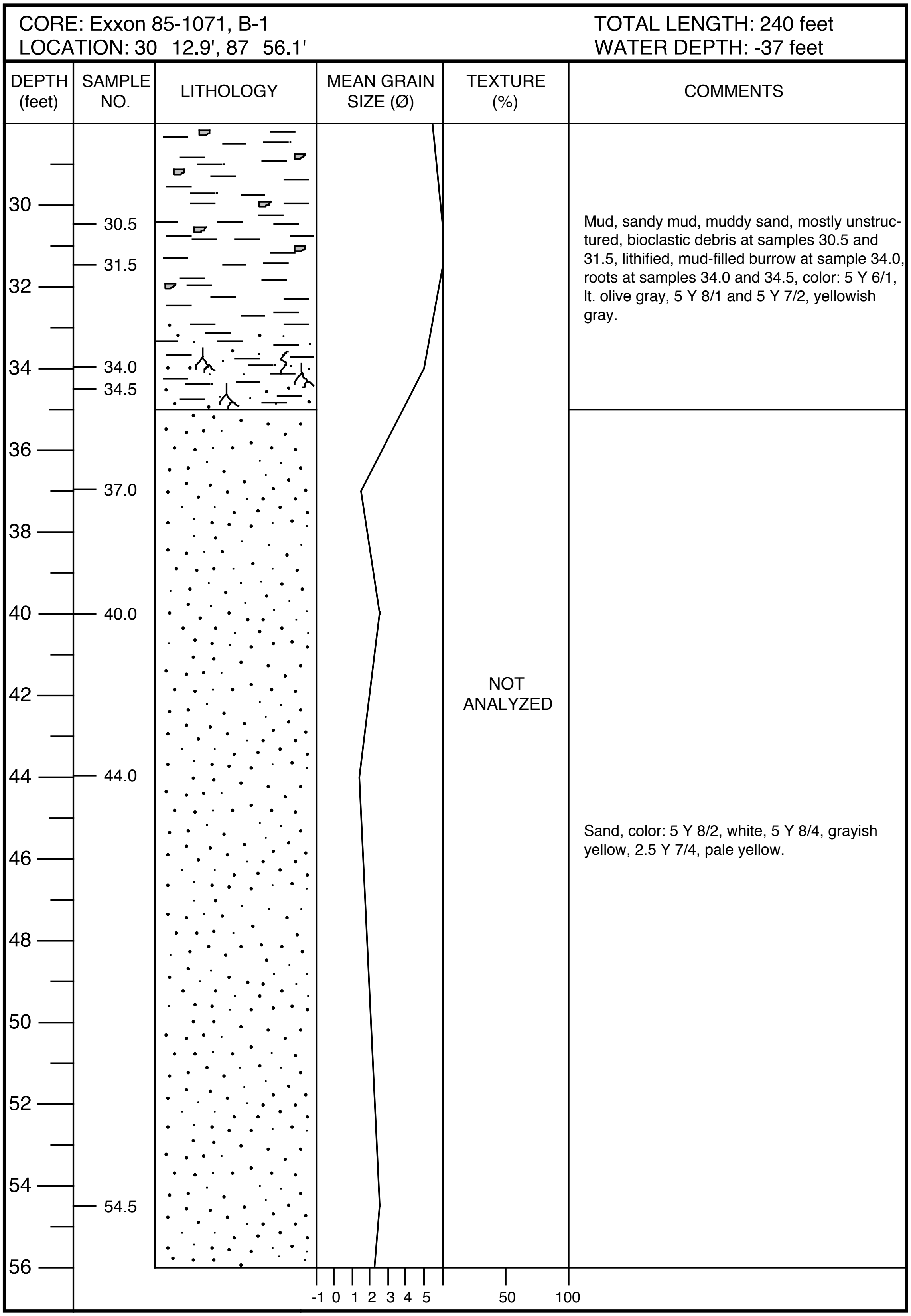


A-55.--Columnar section of EEZ boring Exxon 84-1115, B-1-Continued (modified from Hummell, 1996).



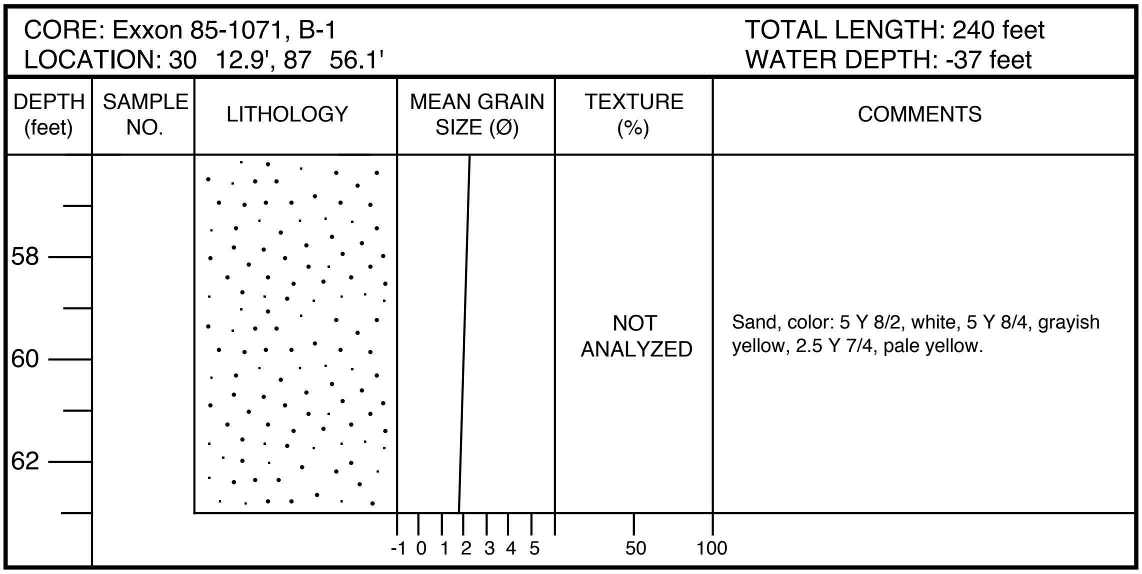
A-56.--Columnar section of EEZ boring Exxon 85-1071, B-1.

CONTINUED FROM PREVIOUS PAGE

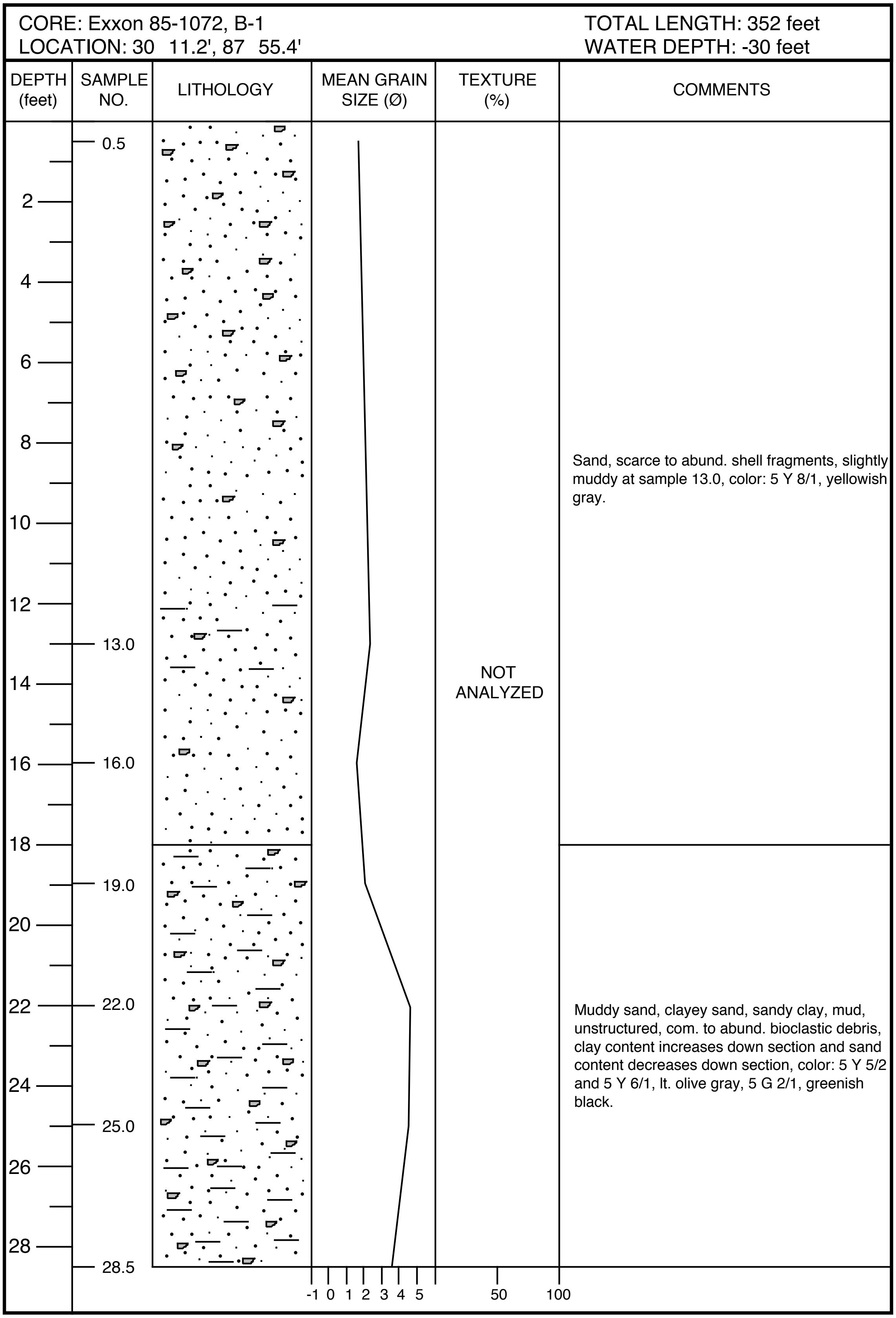


A-56.--Columnar section of EEZ boring Exxon 85-1071, B-1-Continued.

CONTINUED FROM PREVIOUS PAGE

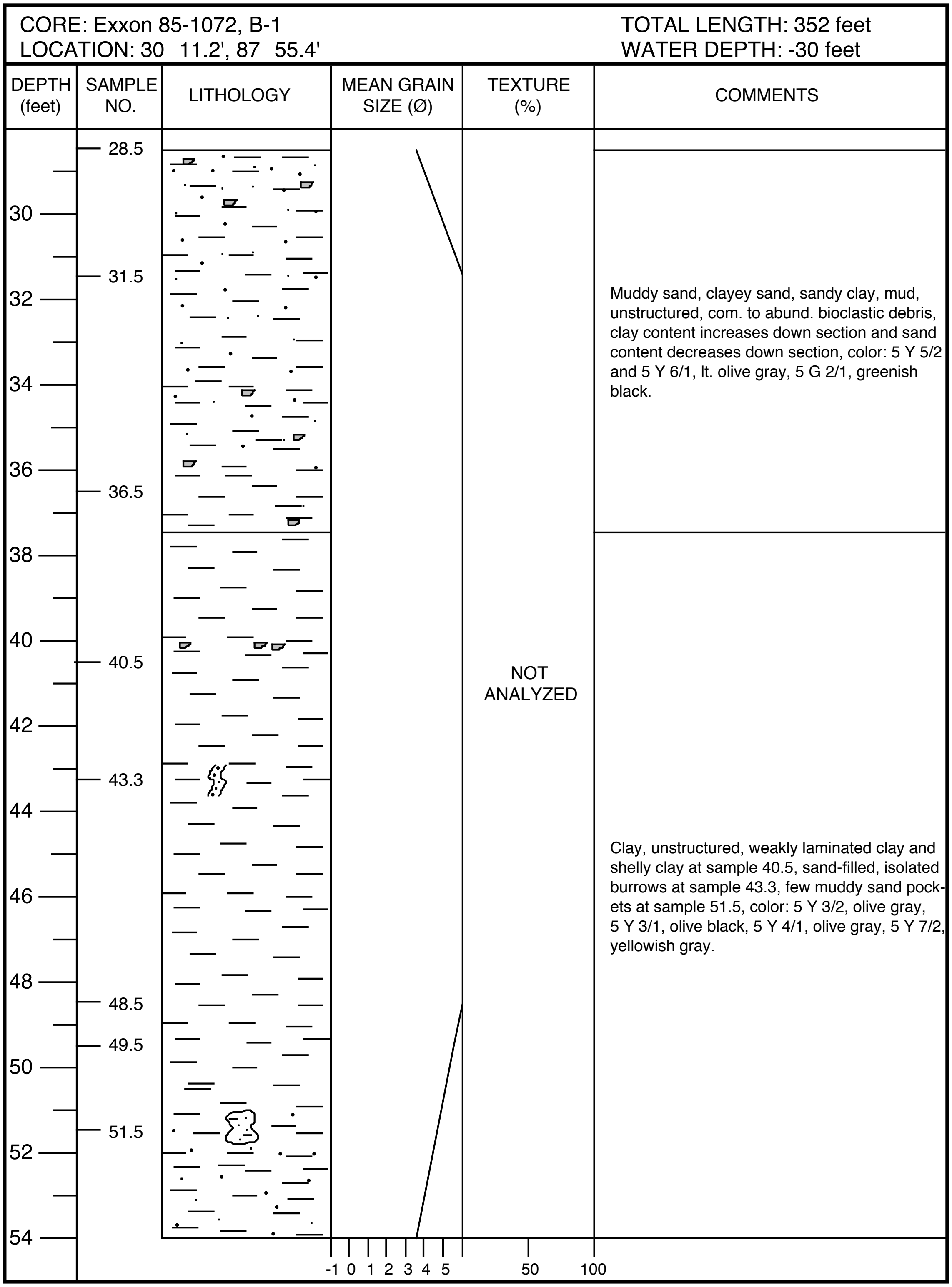


A-56.--Columnar section of EEZ boring Exxon 85-1071, B-1-Continued.

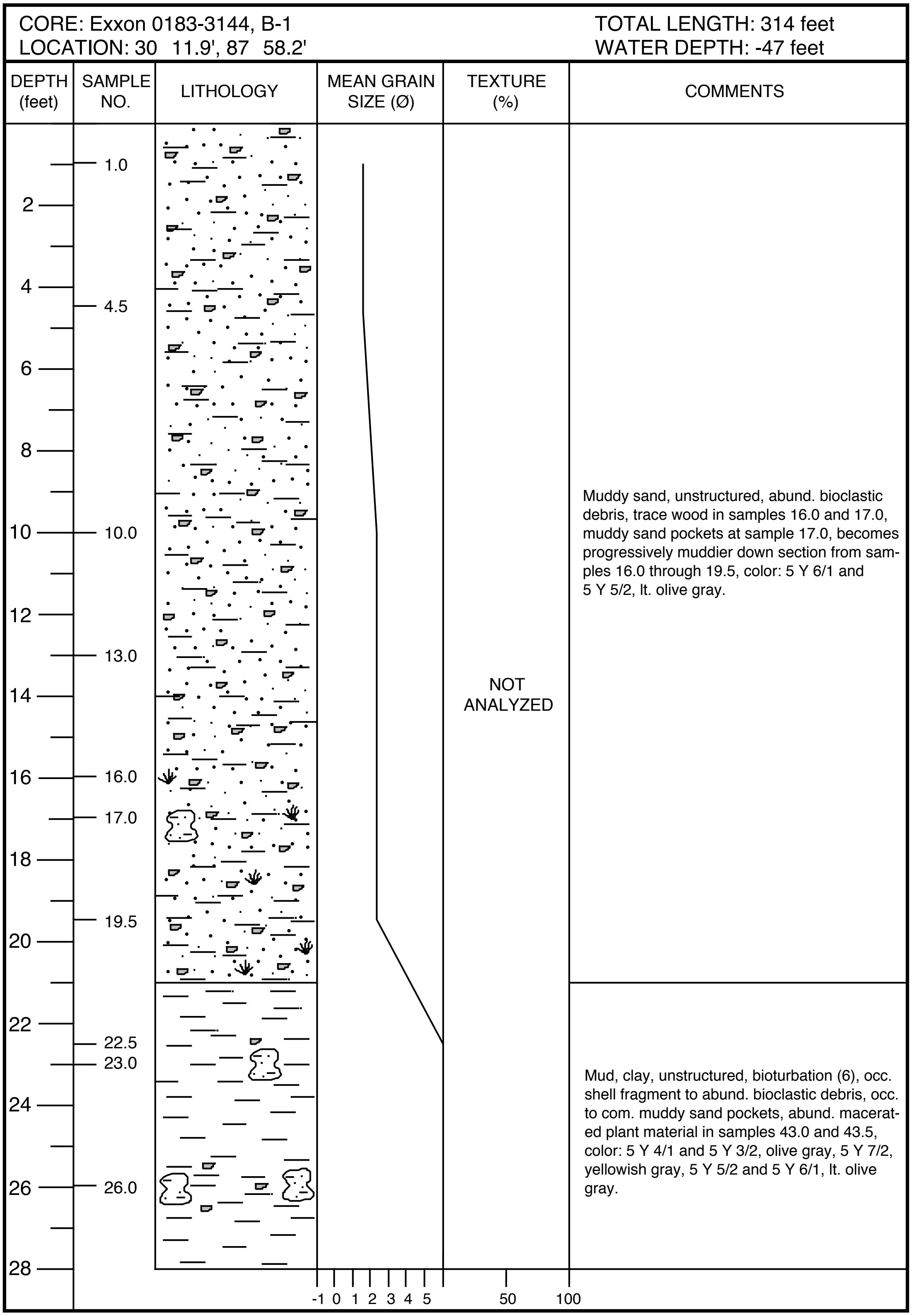


A-57.--Columnar section of EEZ boring Exxon 85-1072, B-1.

CONTINUED FROM PREVIOUS PAGE

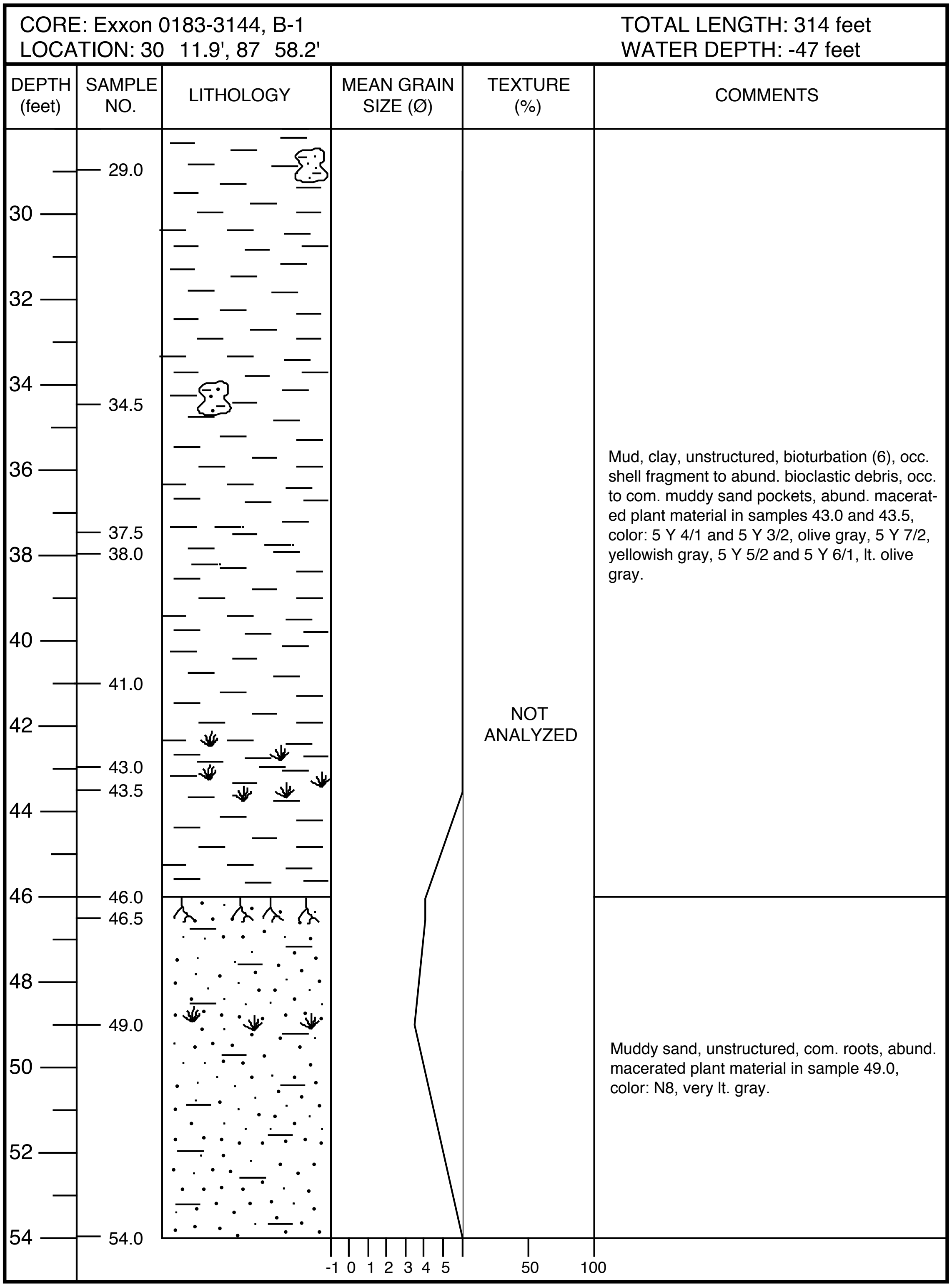


A-57.--Columnar section of EEZ boring Exxon 85-1072, B-1-Continued.

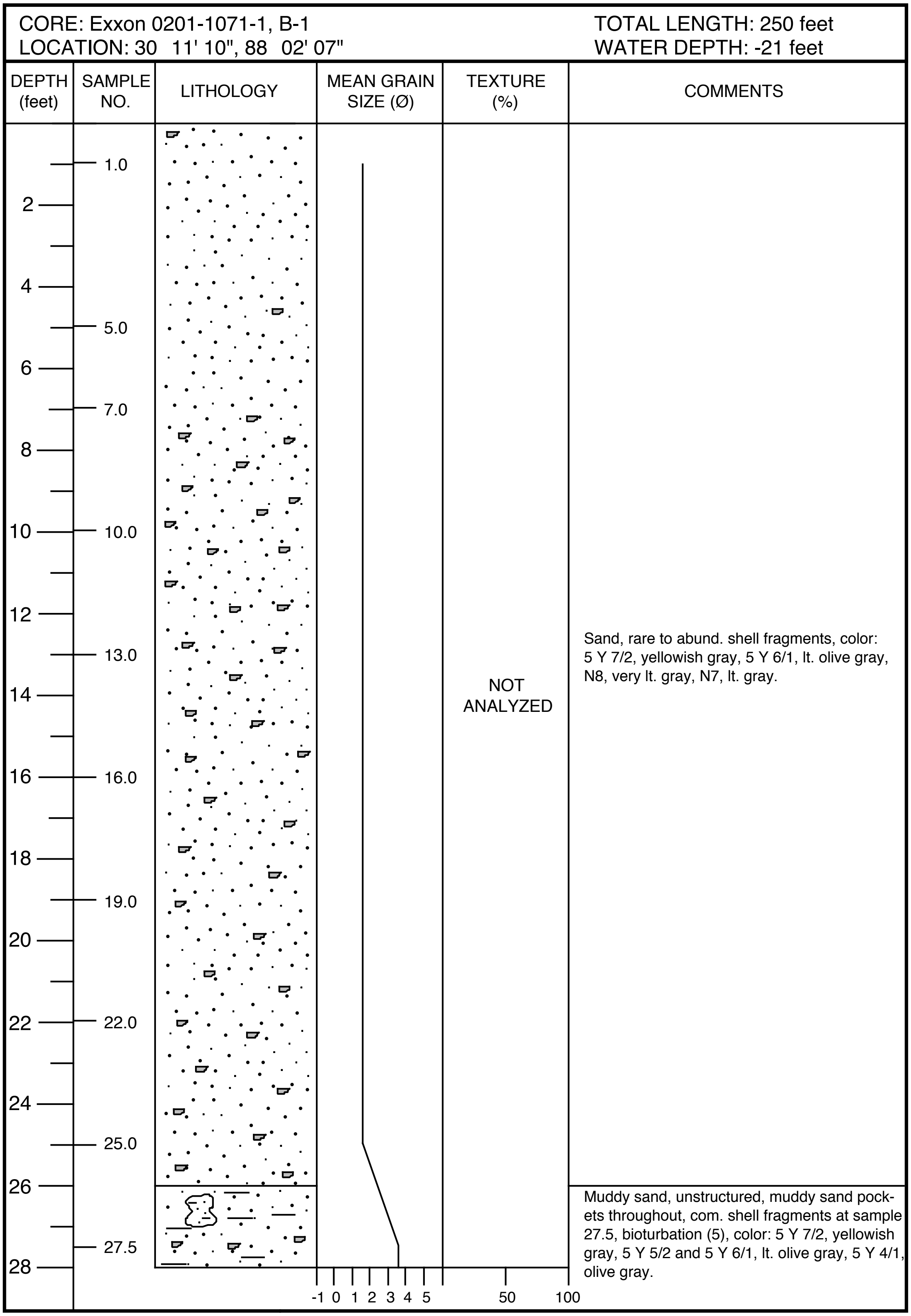


A-58.--Columnar section of EEZ boring Exxon 0183-3144, B-1.

CONTINUED FROM PREVIOUS PAGE

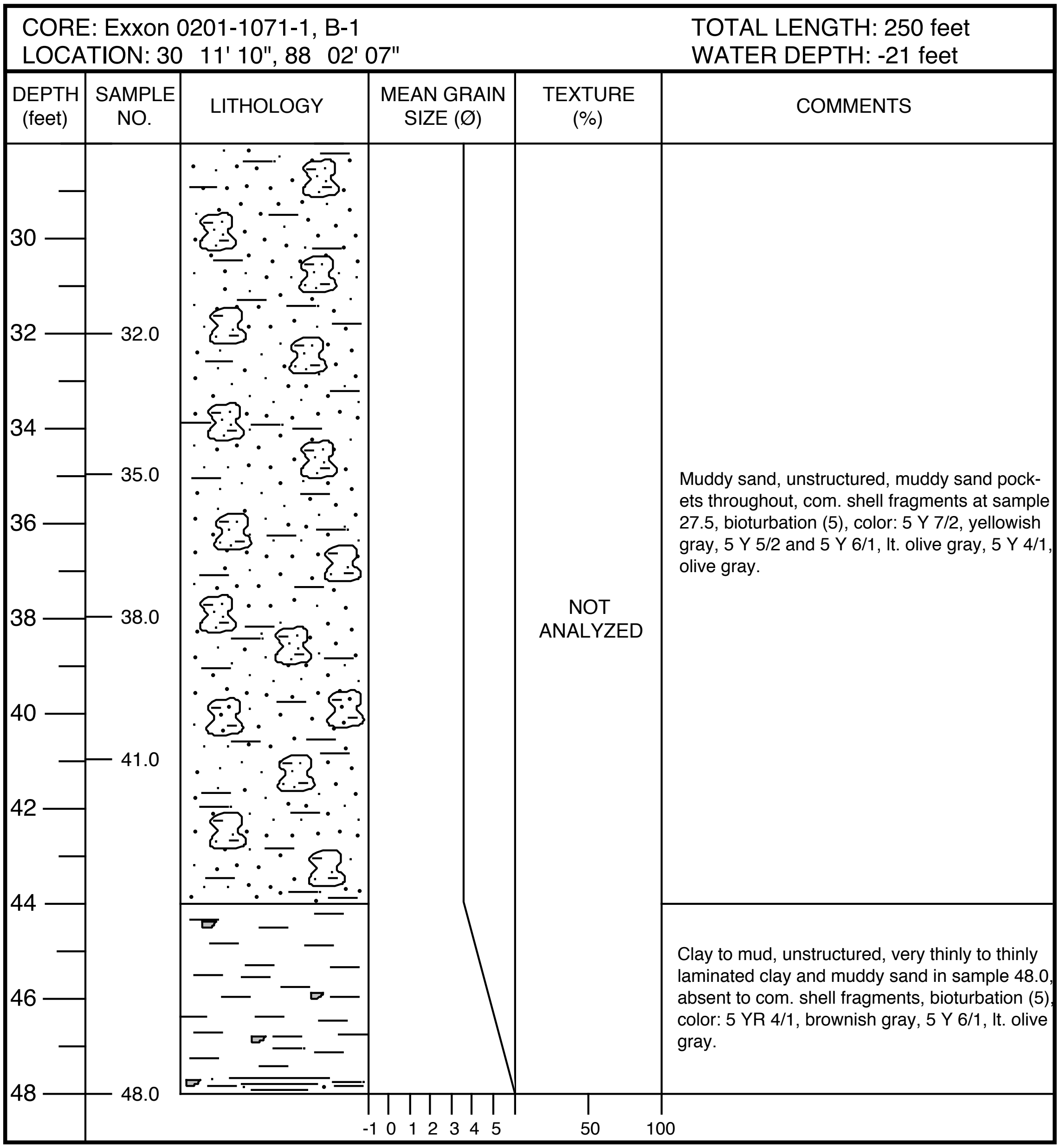


A-58.--Columnar section of EEZ boring Exxon 0183-3144, B-1-Continued.

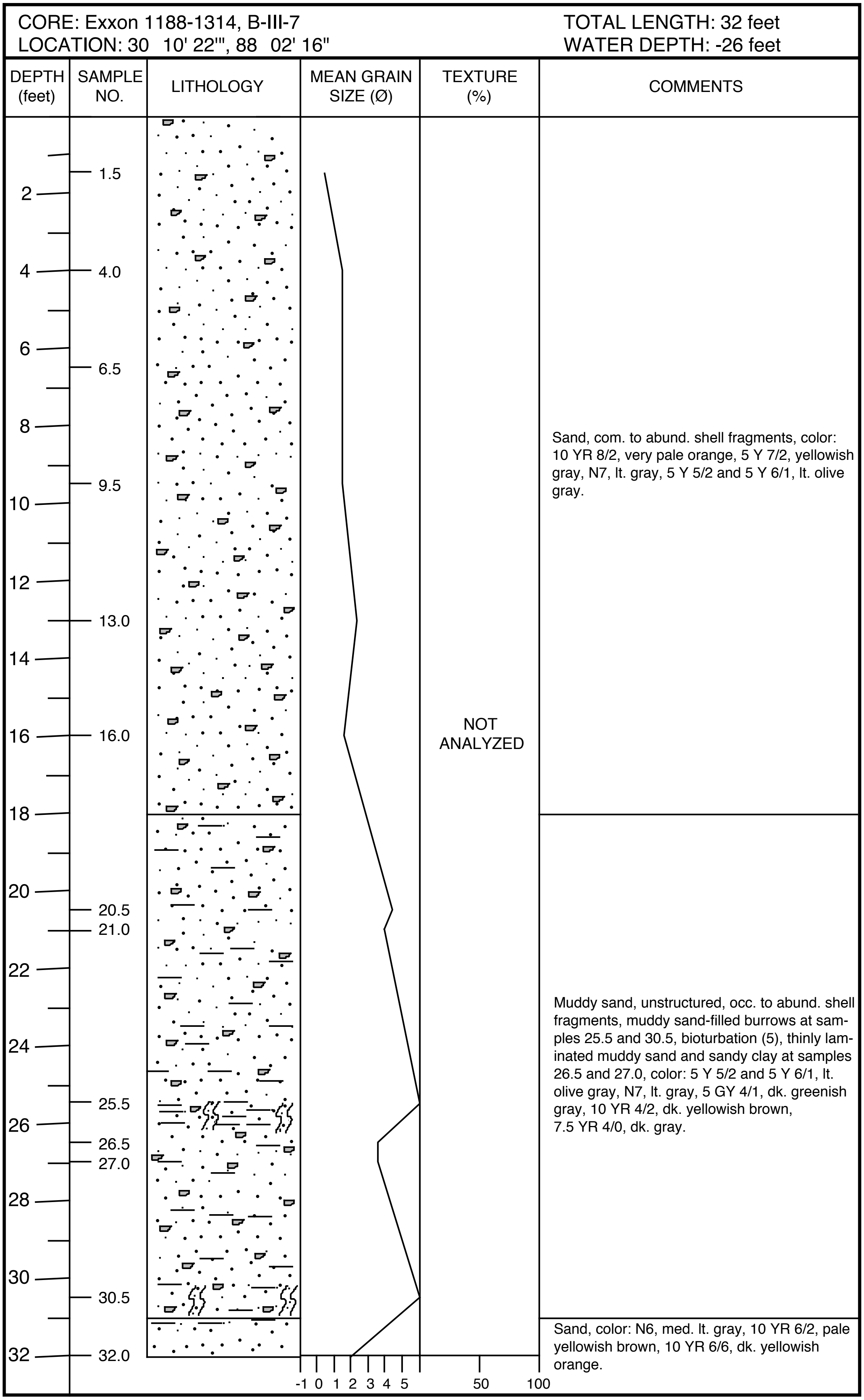


A-59.--Columnar section of EEZ boring Exxon 0201-1071-1, B-1 (modified from Hummell, 1996).

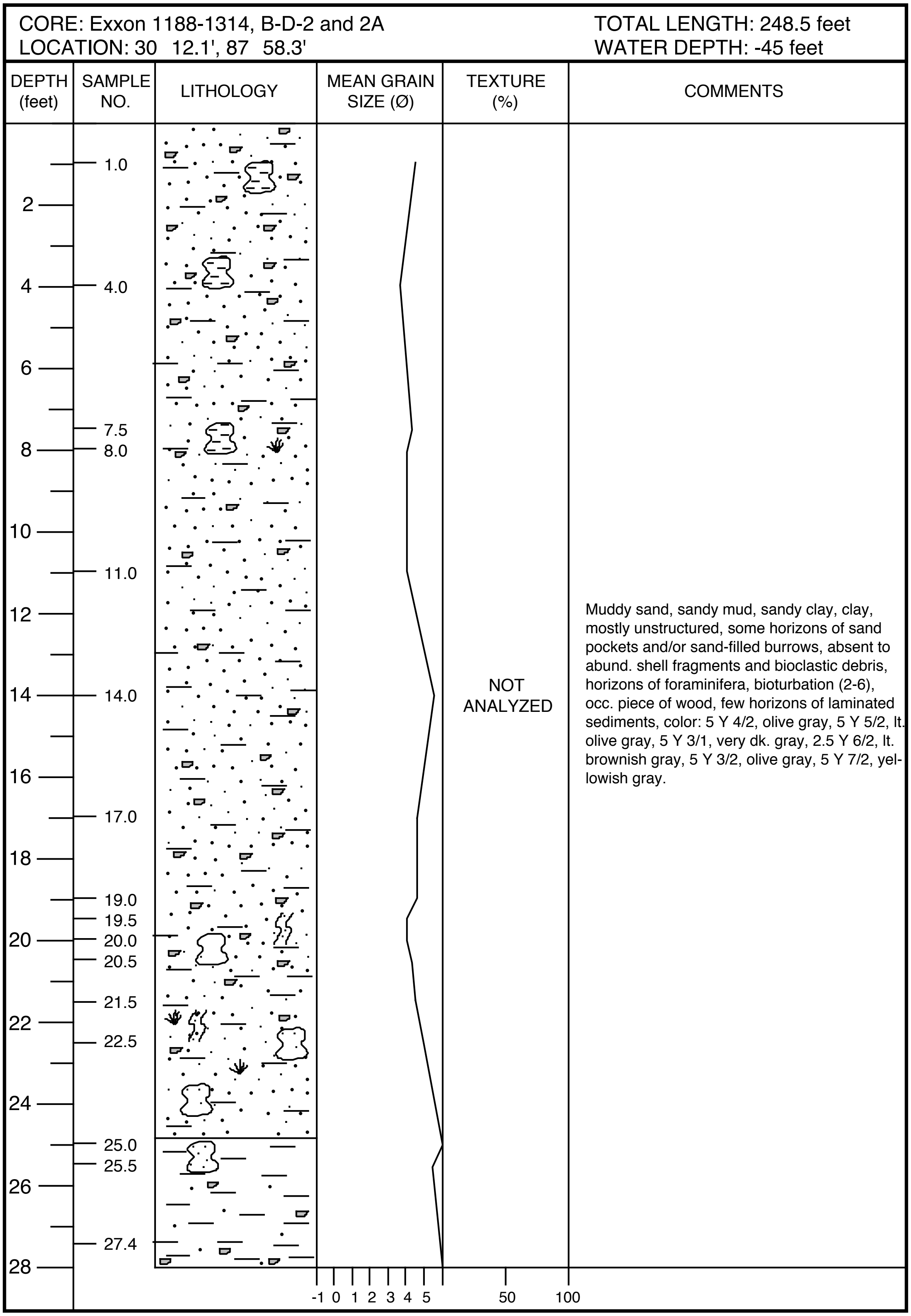
CONTINUED FROM PREVIOUS PAGE



A-59.--Columnar section of EEZ boring Exxon 0201-1071-1, B-1-Continued (modified from Hummell, 1996).

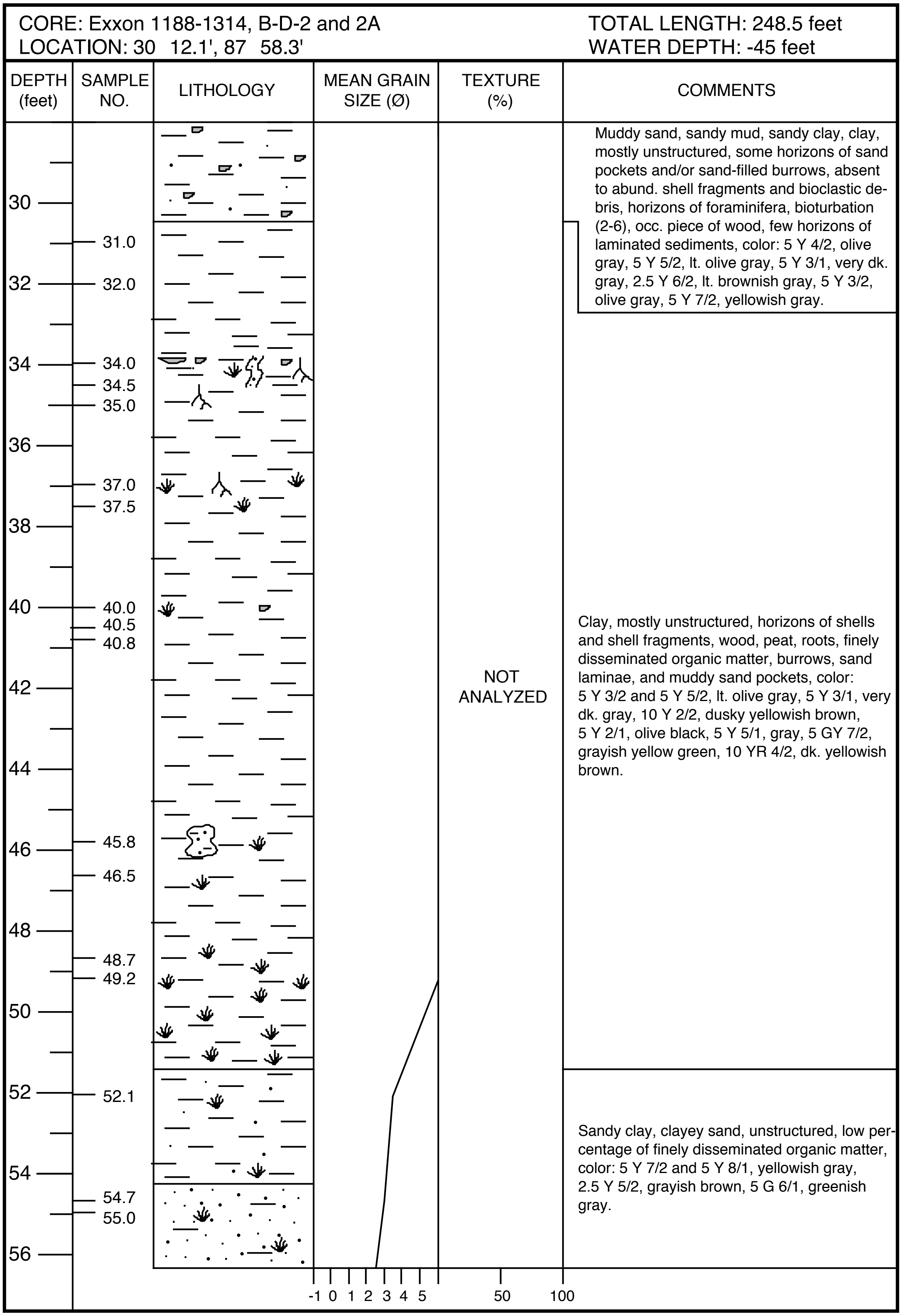


A-60.--Columnar section of EEZ boring Exxon 1188-1314, B-III-7 (modified from Hummell, 1996).

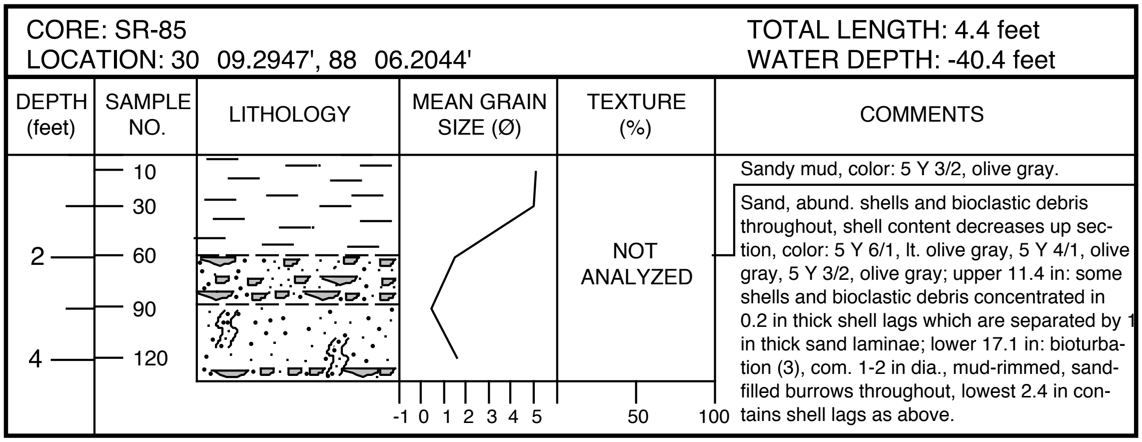


A-61.--Columnar section of EEZ boring Exxon 1188-1314, B-D-2 and 2A.

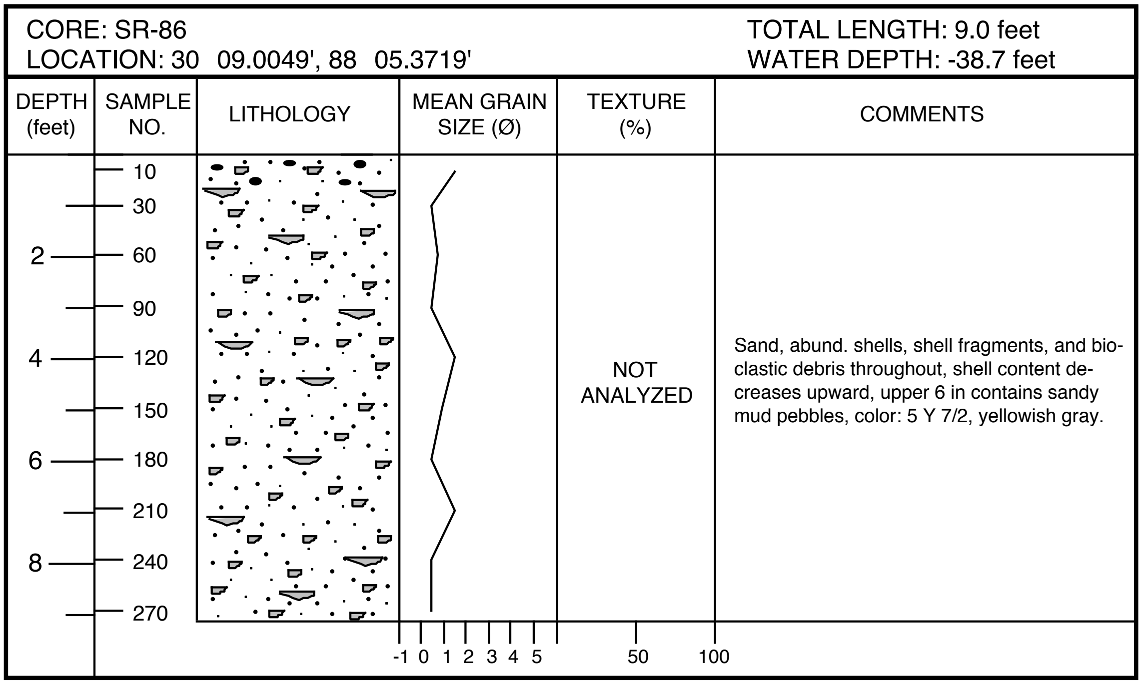
CONTINUED FROM PREVIOUS PAGE



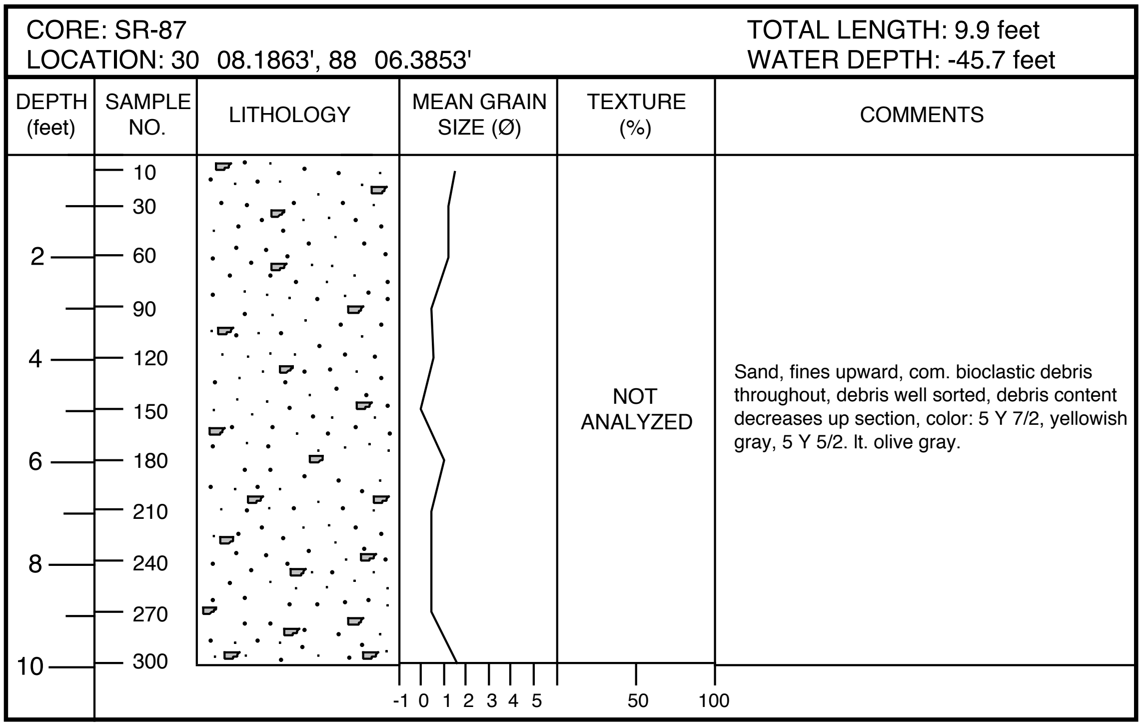
A-61.--Columnar section of EEZ boring Exxon 1188-1314, B-D-2 and 2A-Continued.



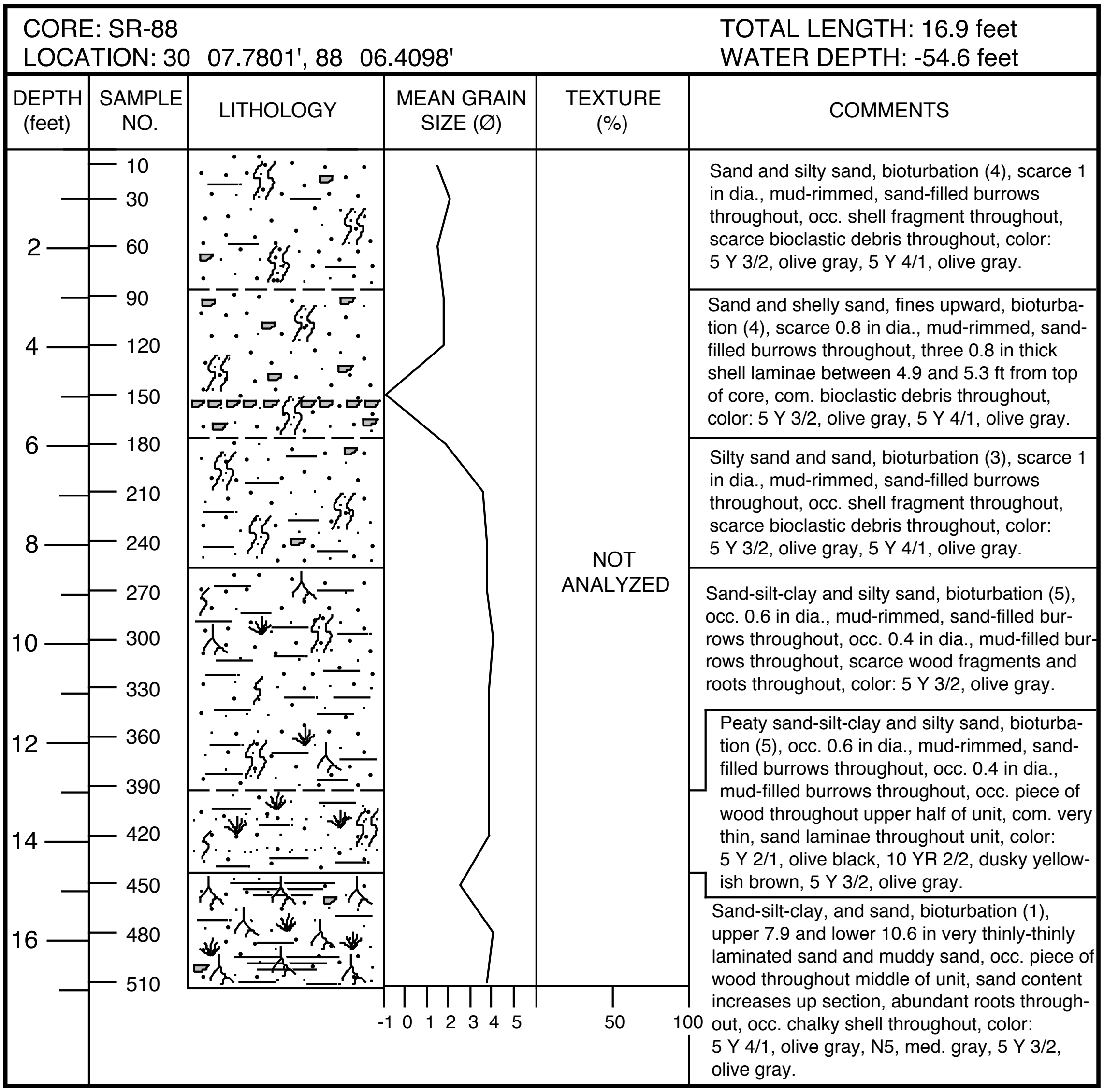
A-62.--Columnar section of EEZ vibracore SR-85.



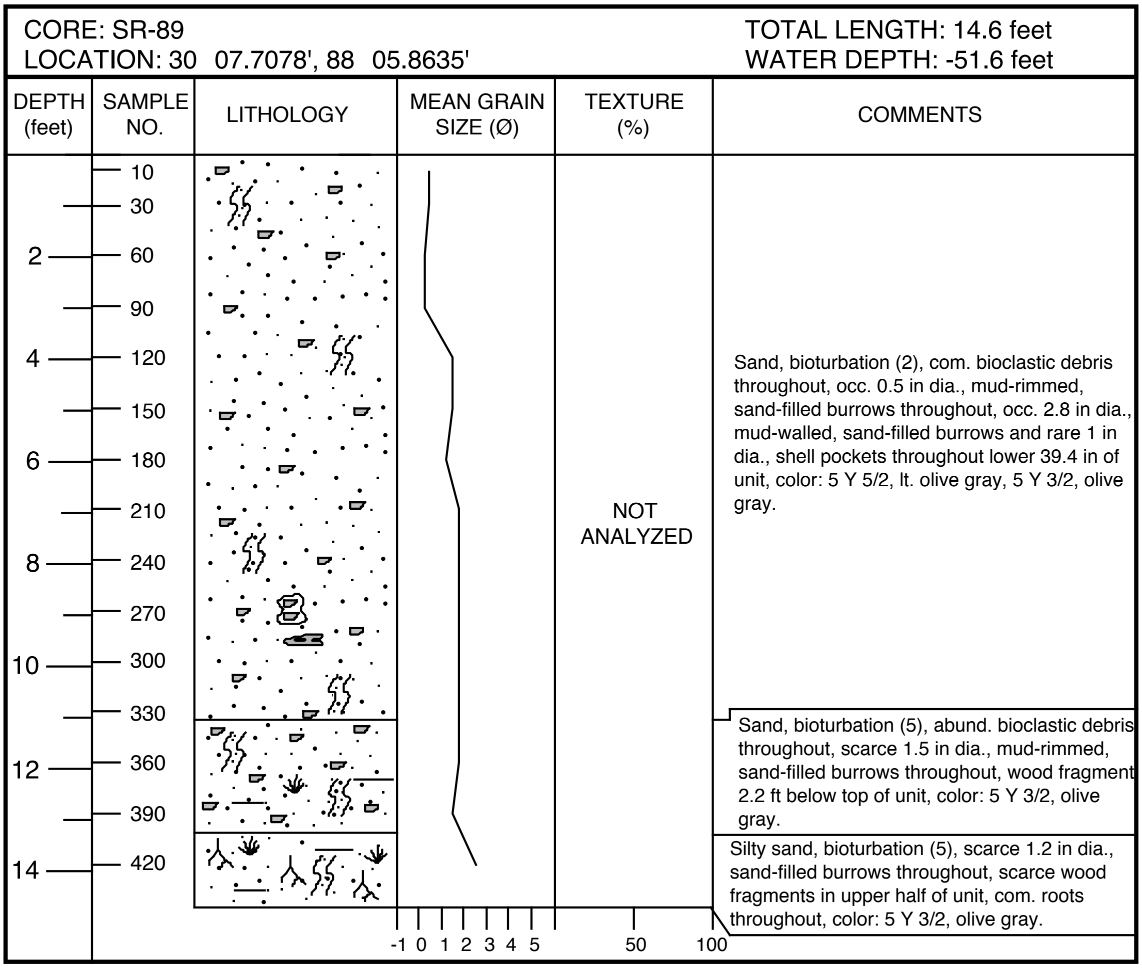
A-63.--Columnar section of EEZ vibracore SR-86.



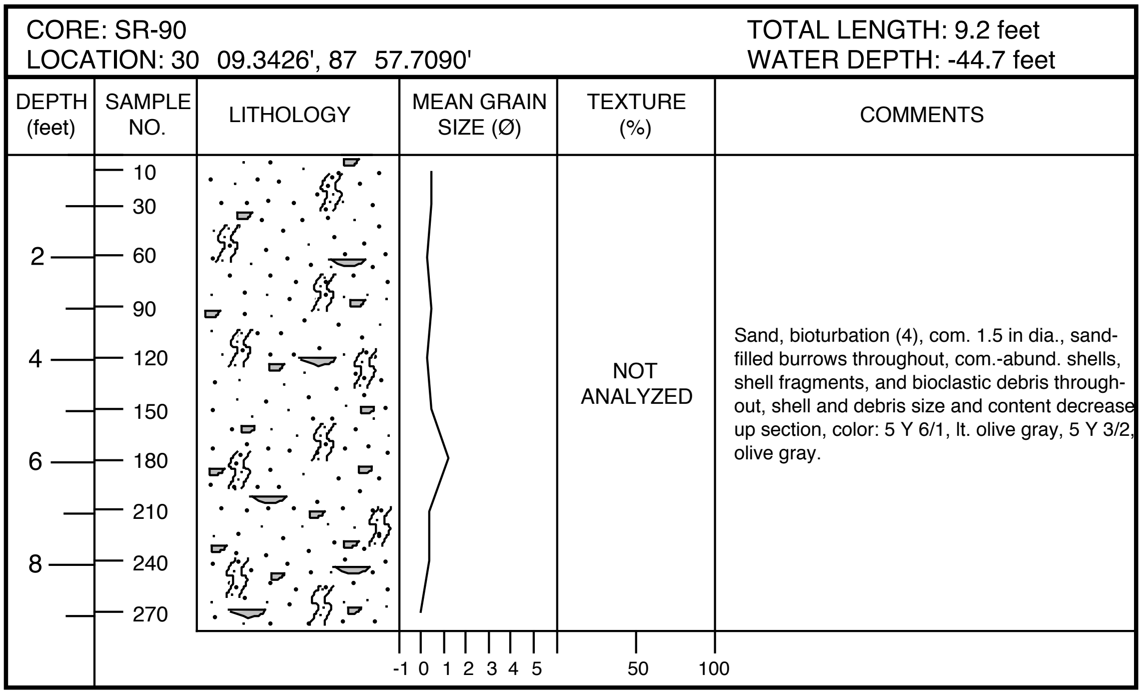
A-64.--Columnar section of EEZ vibracore SR-87.



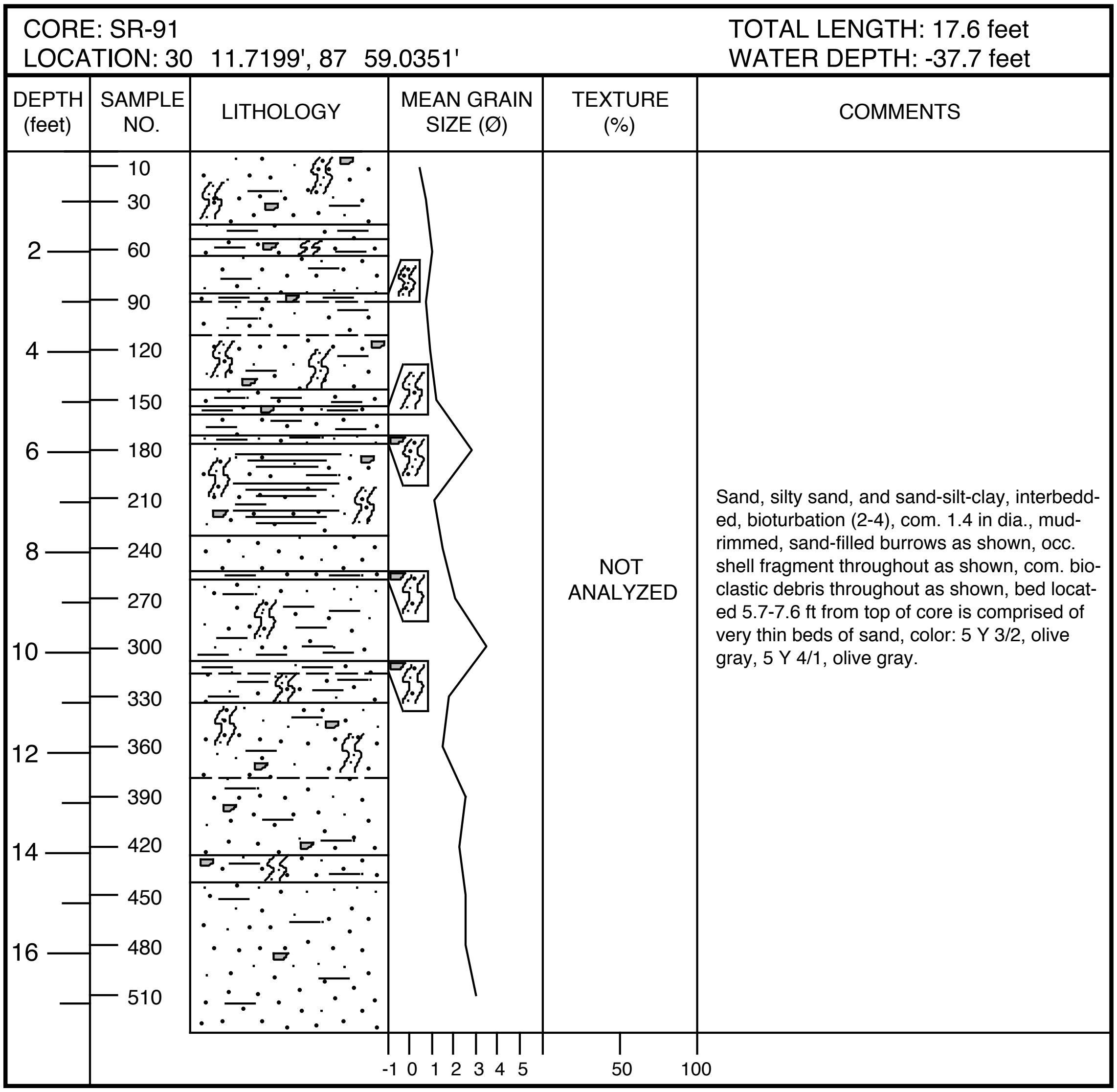
A-65.--Columnar section of EEZ vibracore SR-88.



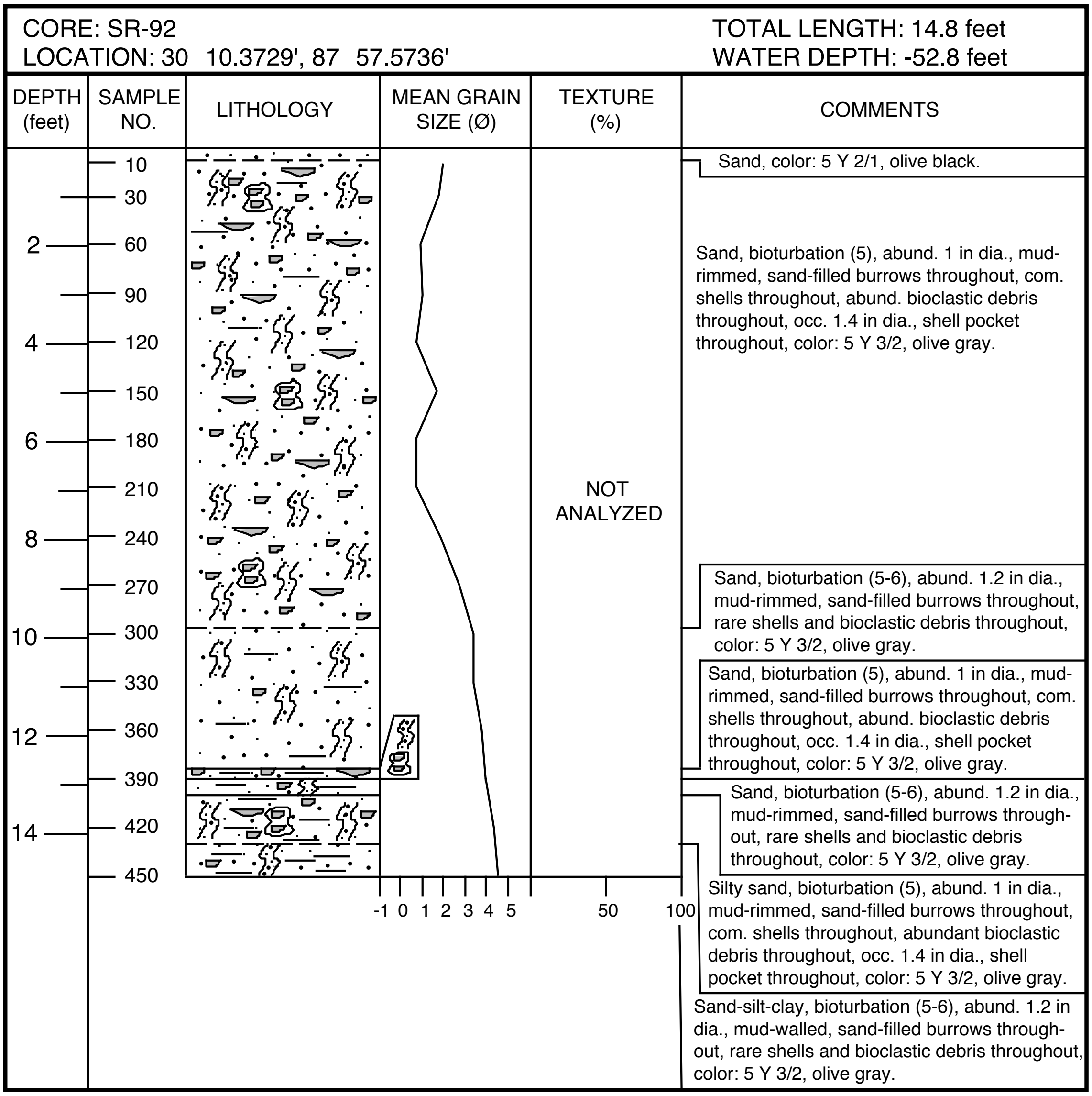
A-66.--Columnar section of EEZ vibracore SR-89.



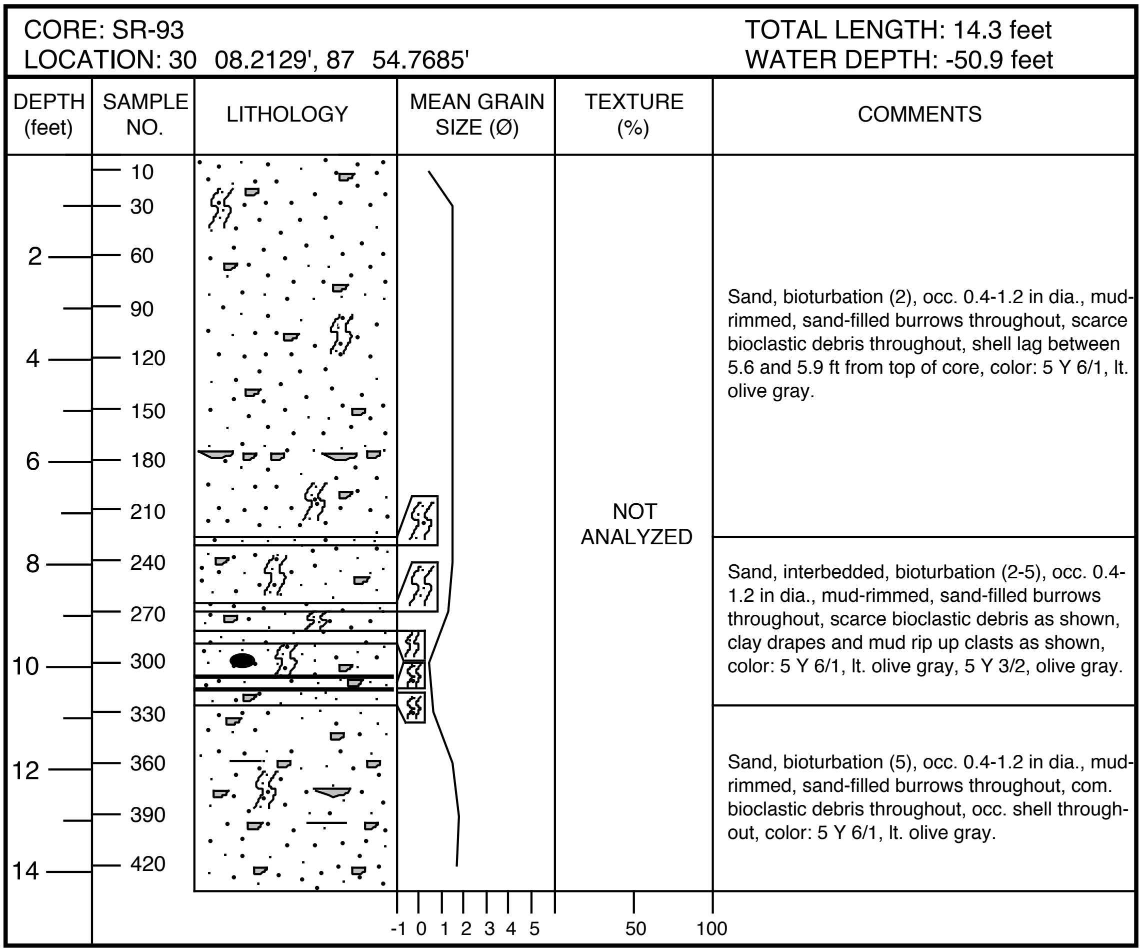
A-67.--Columnar section of EEZ vibracore SR-90.



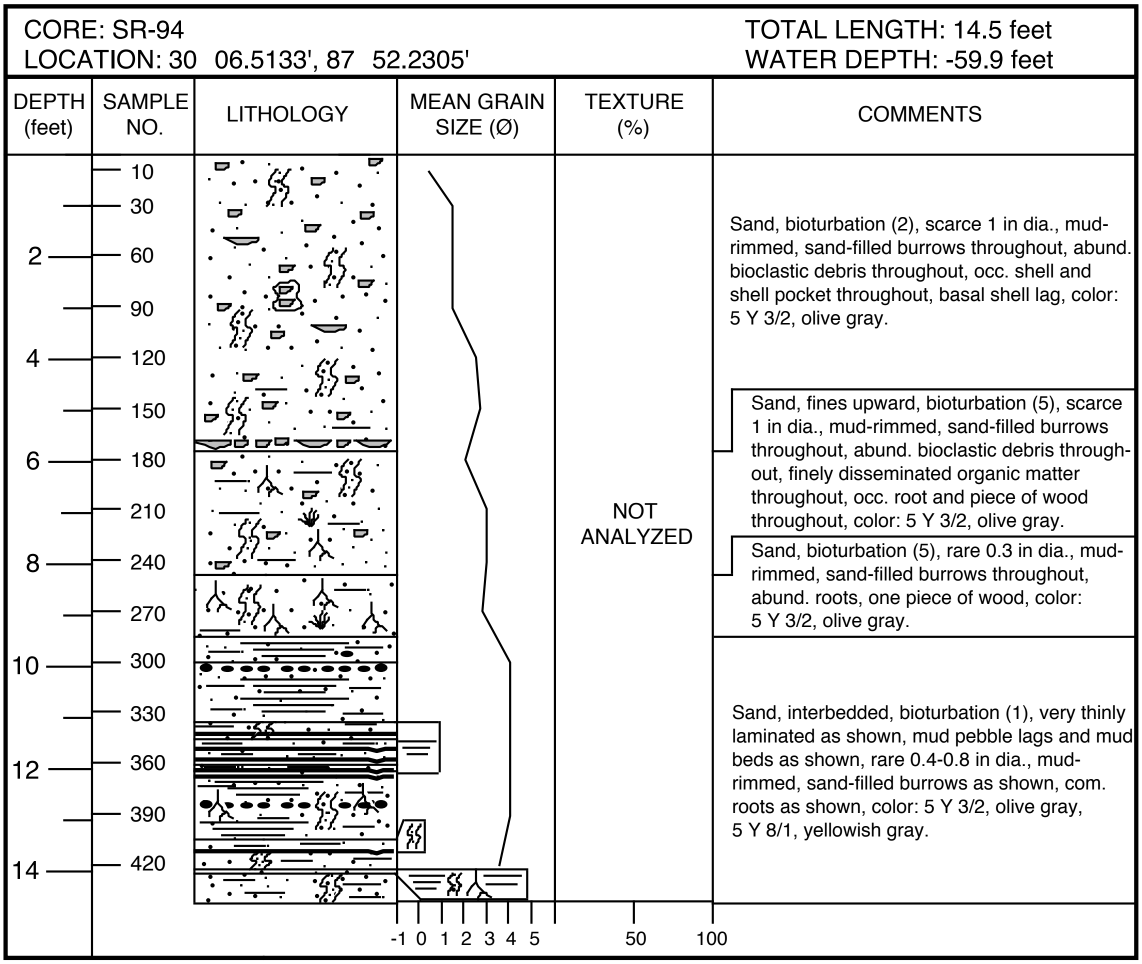
A-68.--Columnar section of EEZ vibracore SR-91.



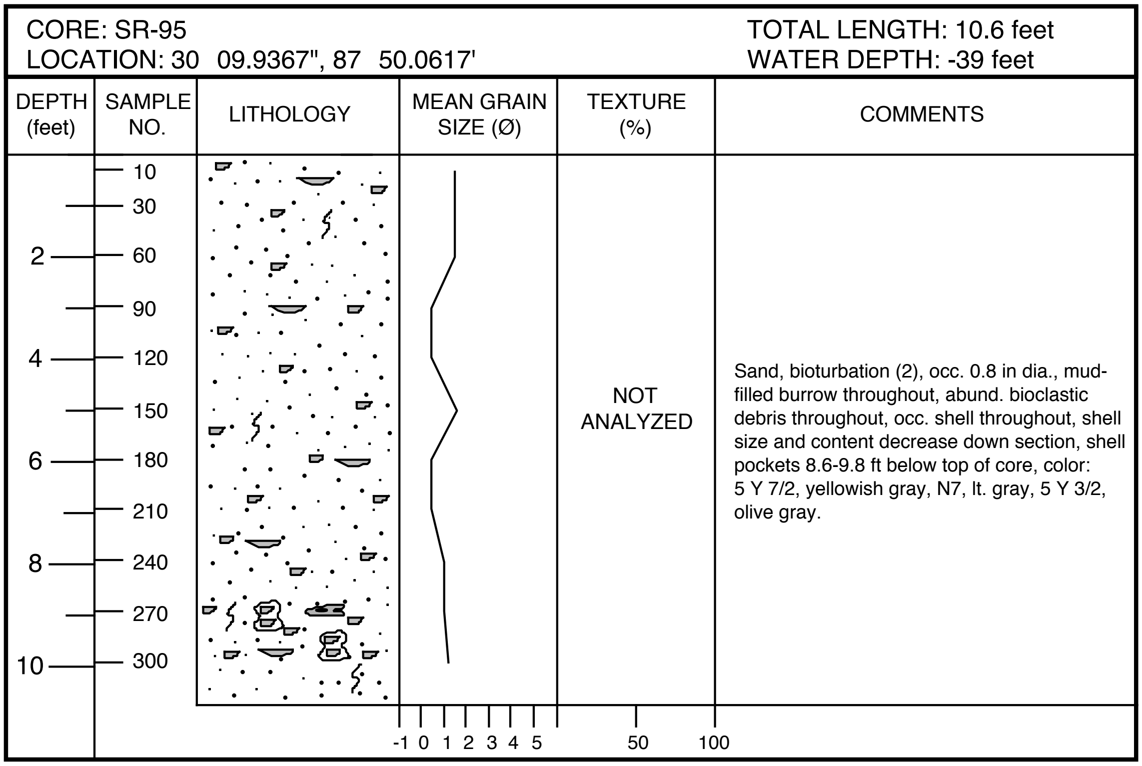
A-69.--Columnar section of EEZ vibracore SR-92.



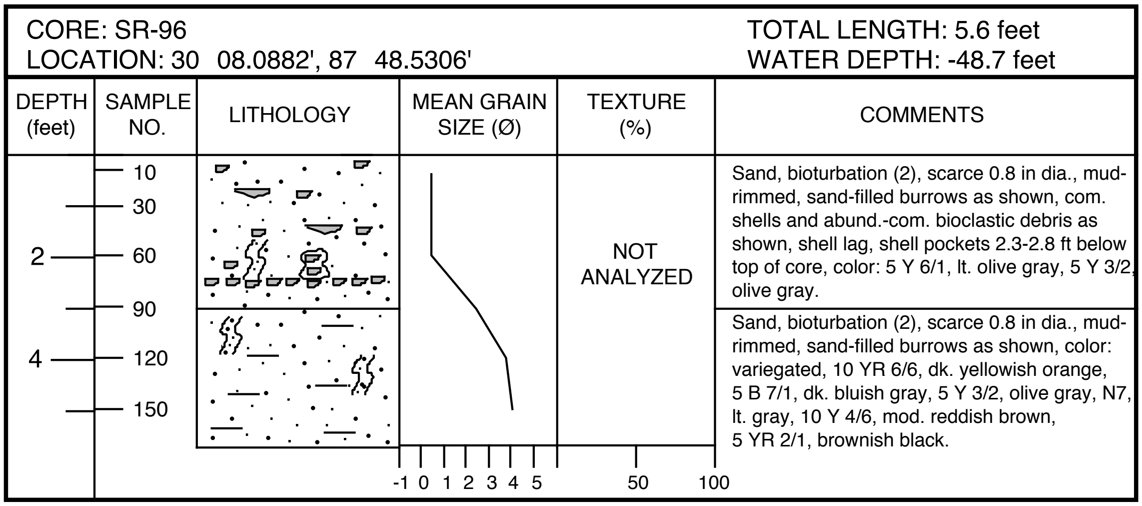
A-70.--Columnar section of EEZ vibracore SR-93.



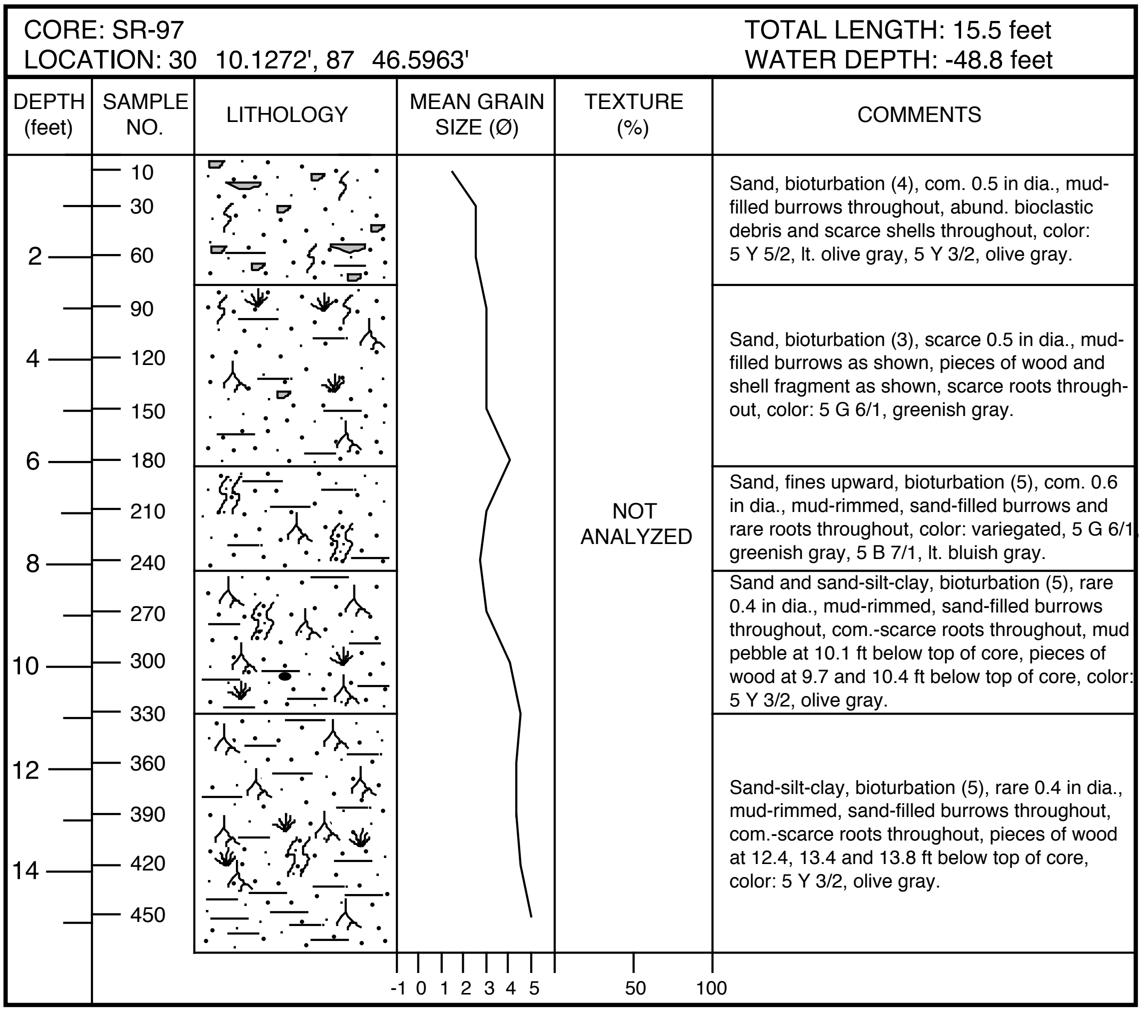
A-71.--Columnar section of EEZ vibracore SR-94.



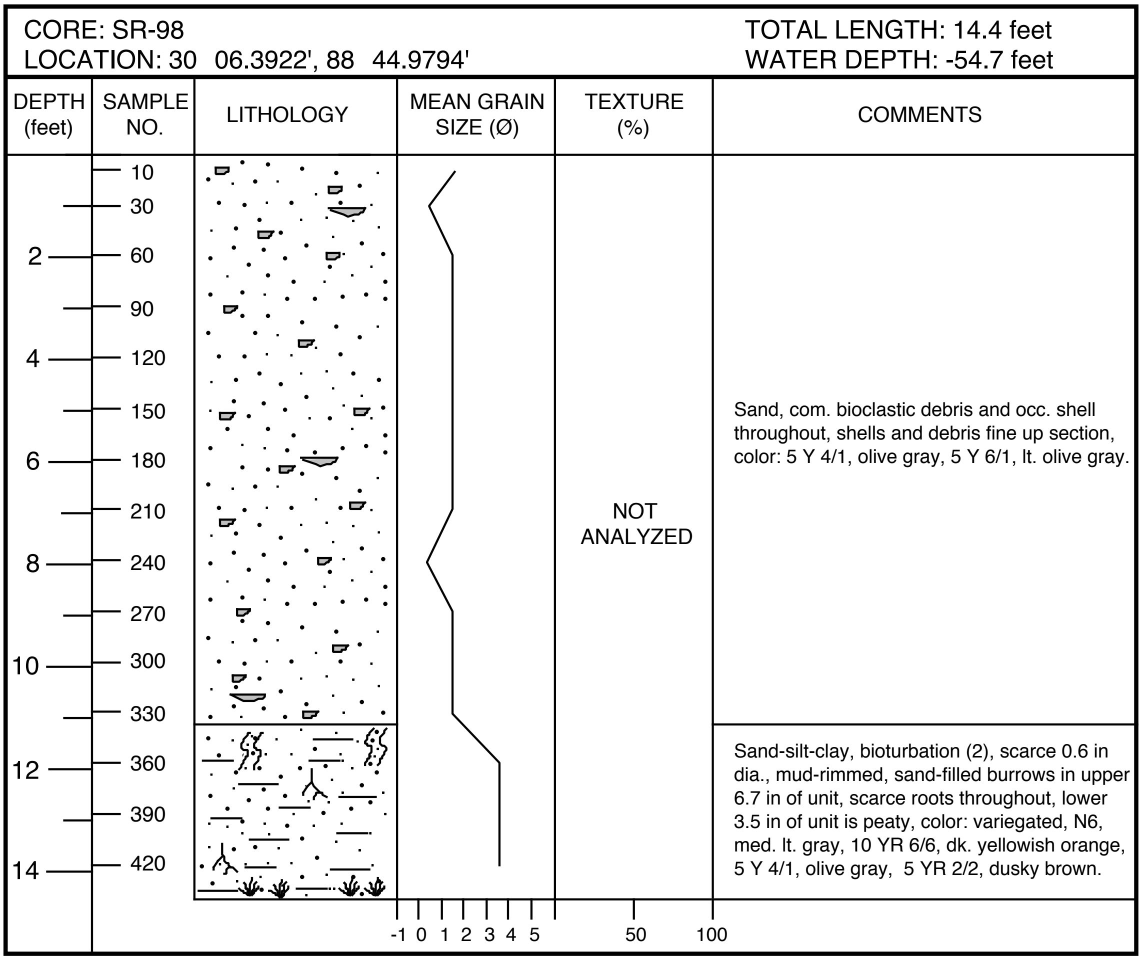
A-72.--Columnar section of EEZ vibracore SR-95.



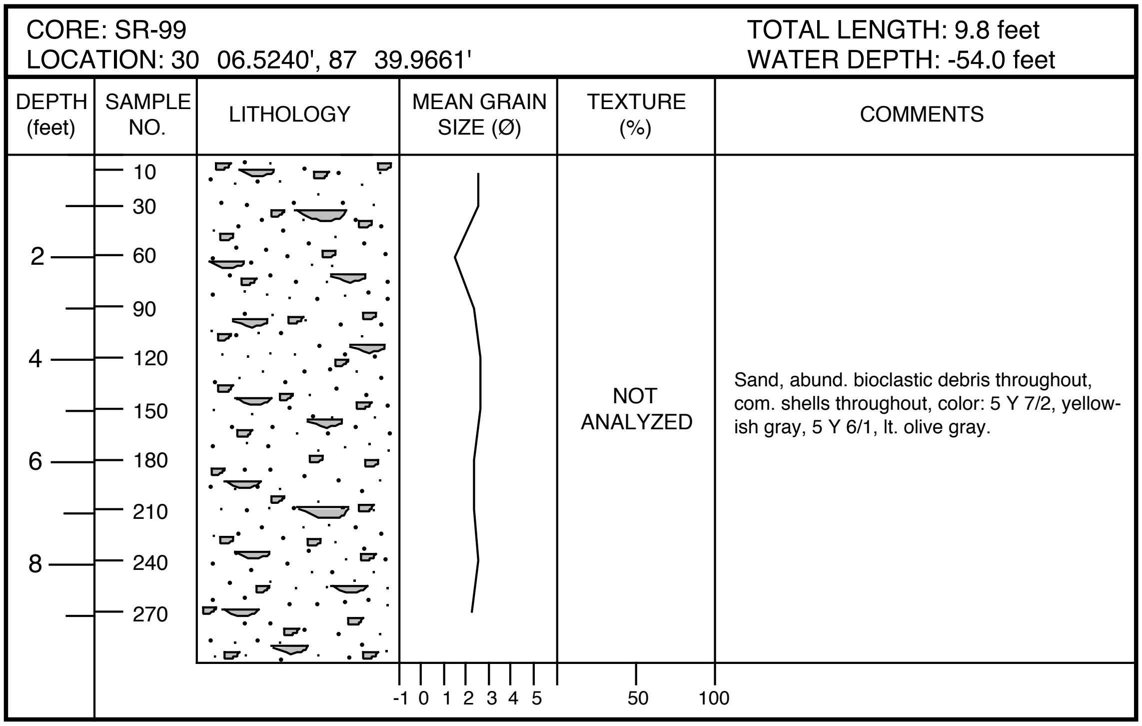
A-73.--Columnar section of EEZ vibracore SR-96.



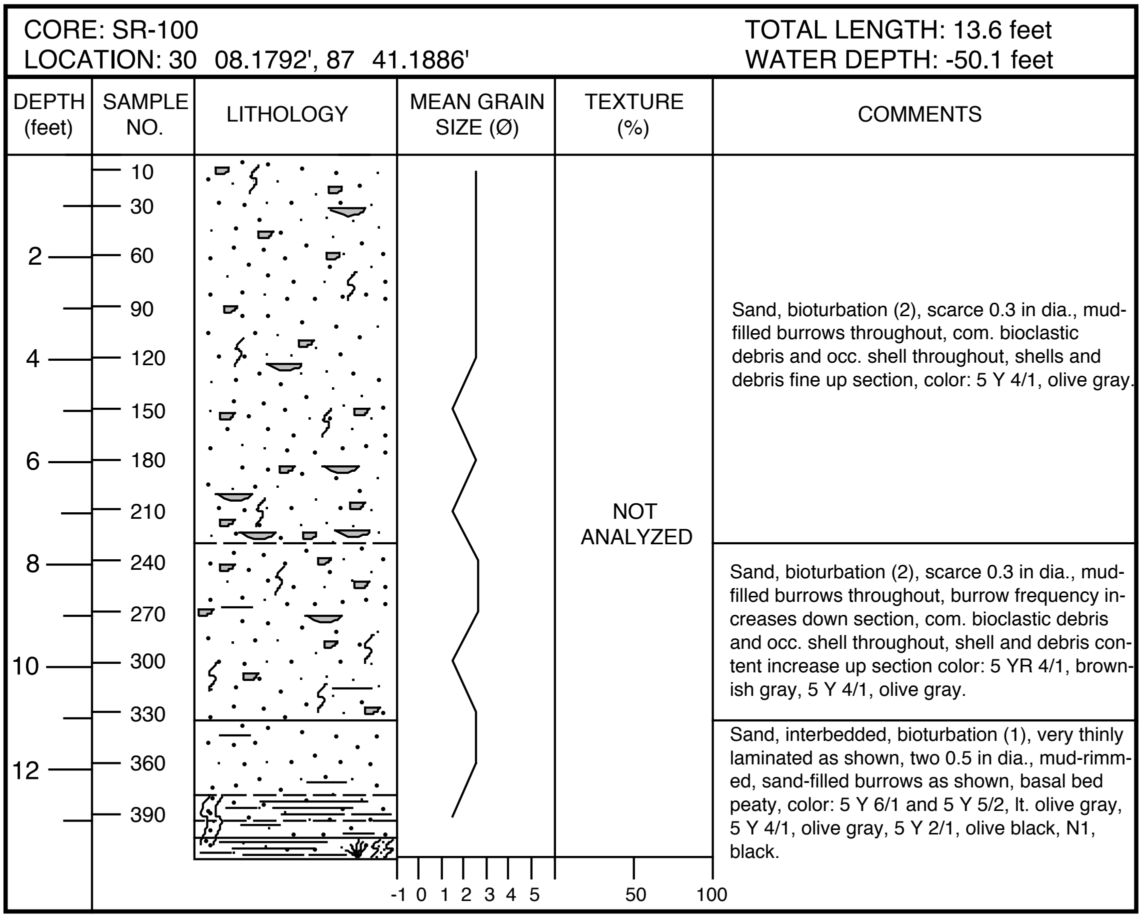
A-74.--Columnar section of EEZ vibracore SR-97.



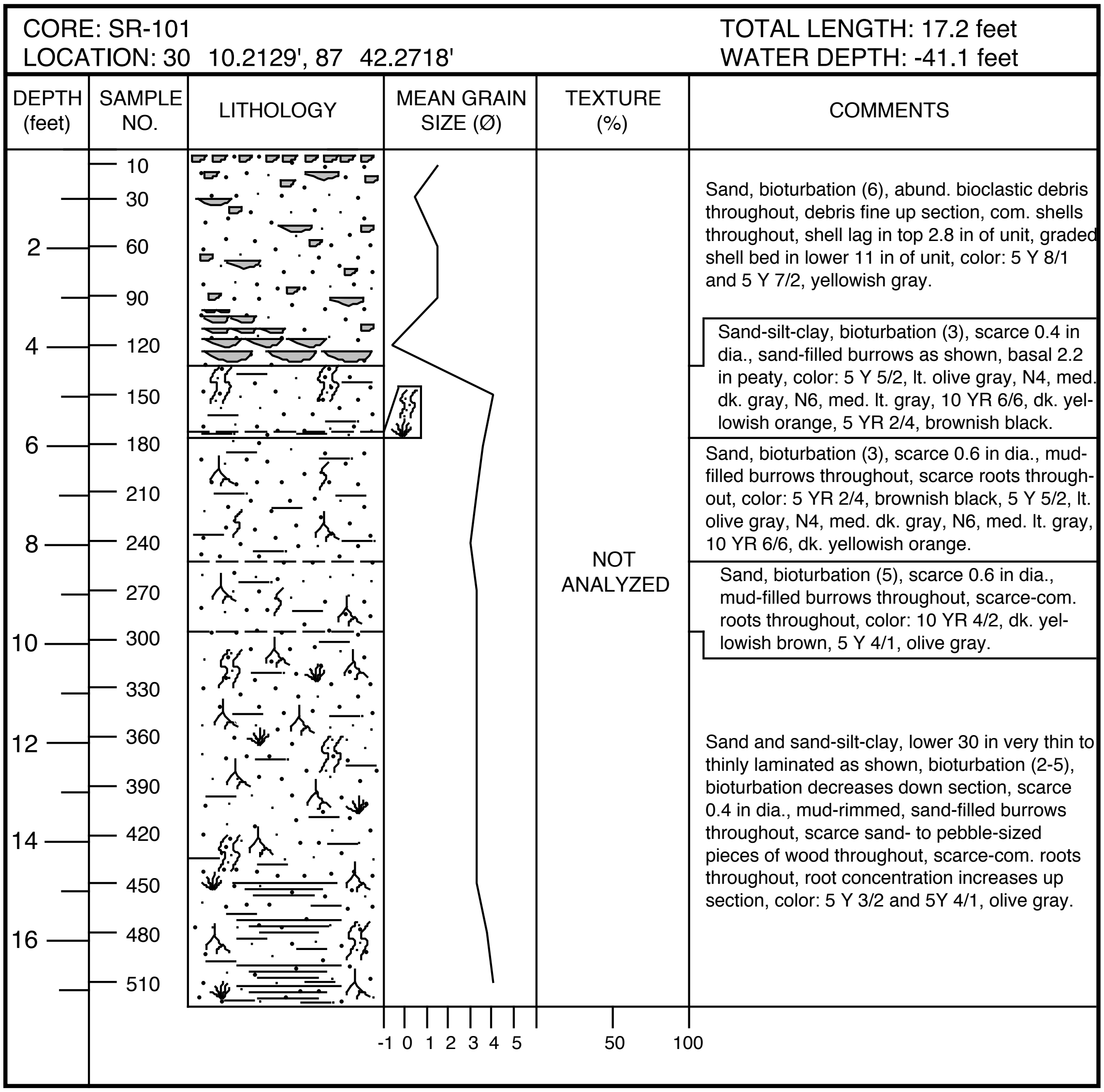
A-75.--Columnar section of EEZ vibracore SR-98.



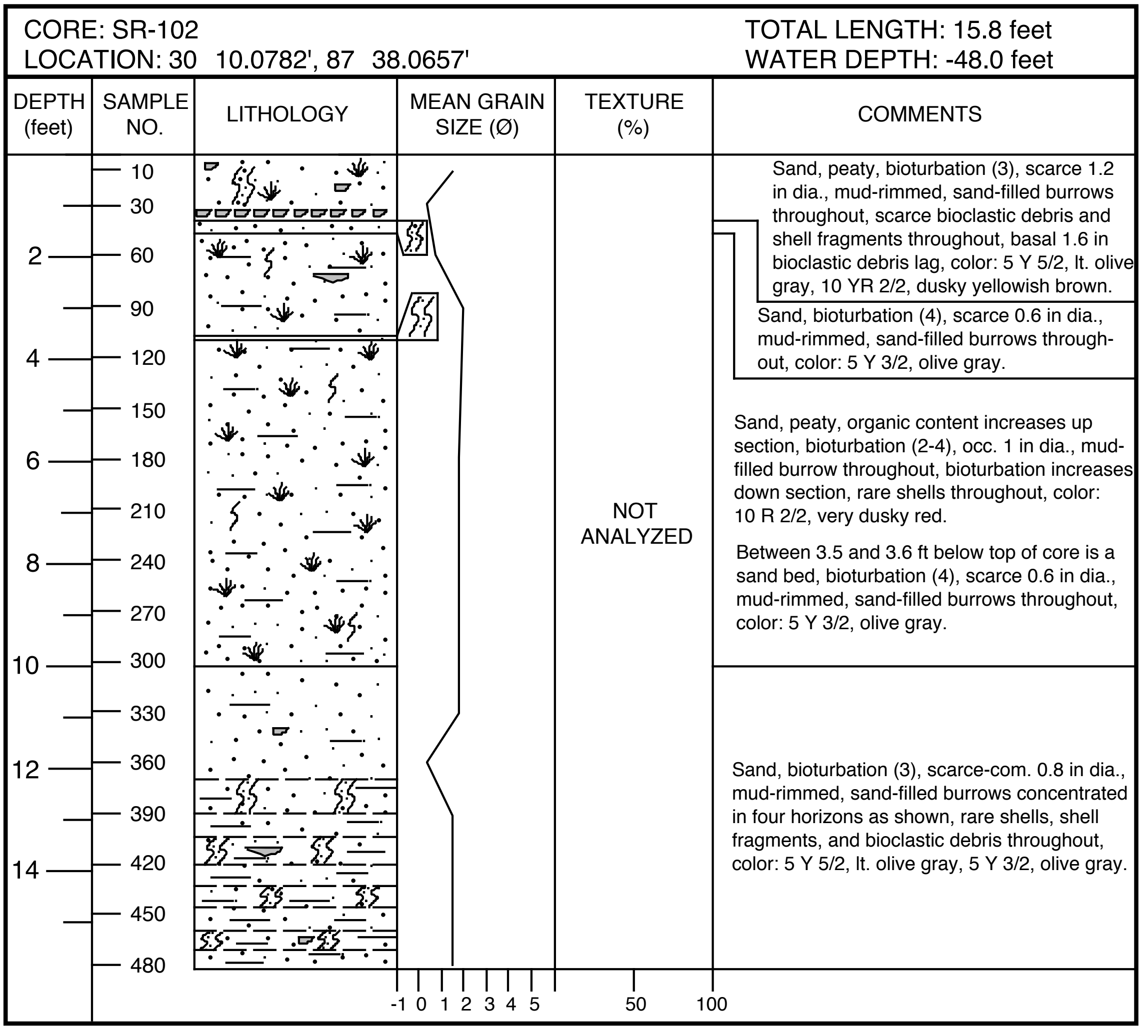
A-76.--Columnar section of EEZ vibracore SR-99.



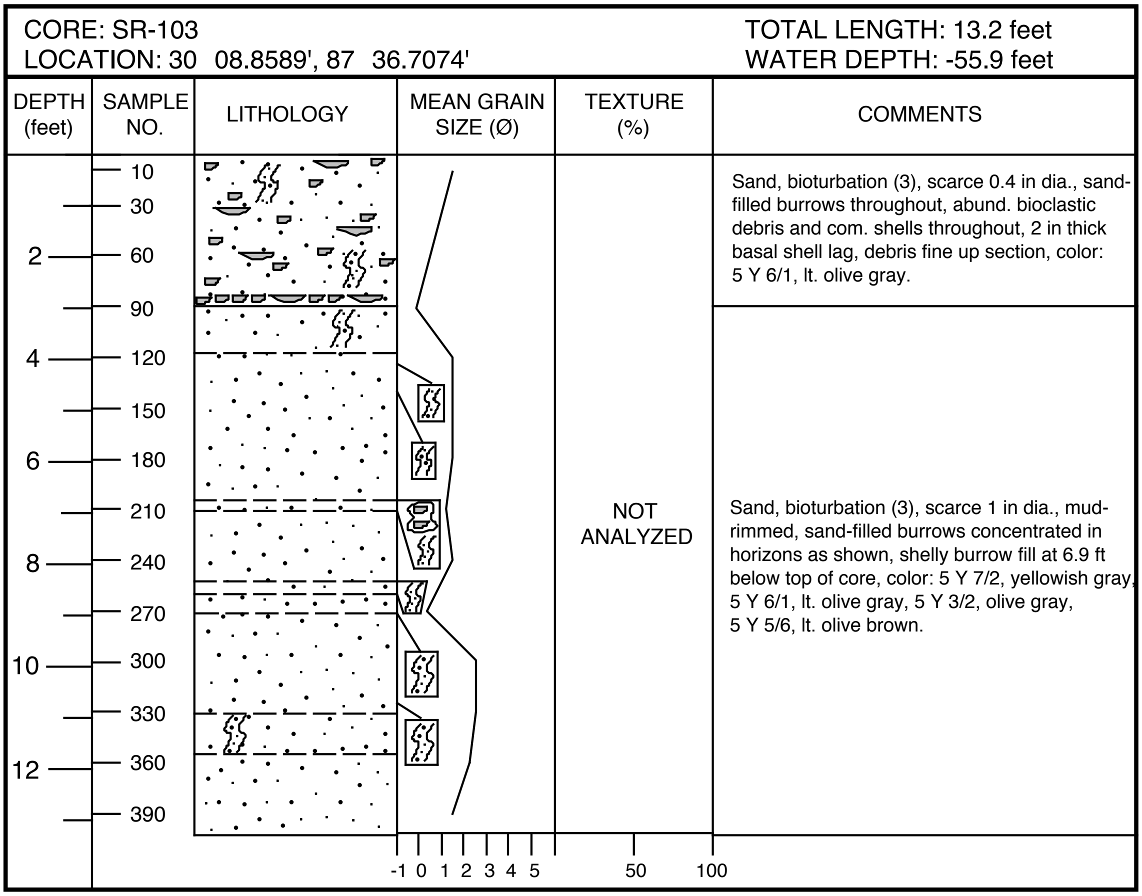
A-77.--Columnar section of EEZ vibracore SR-100.



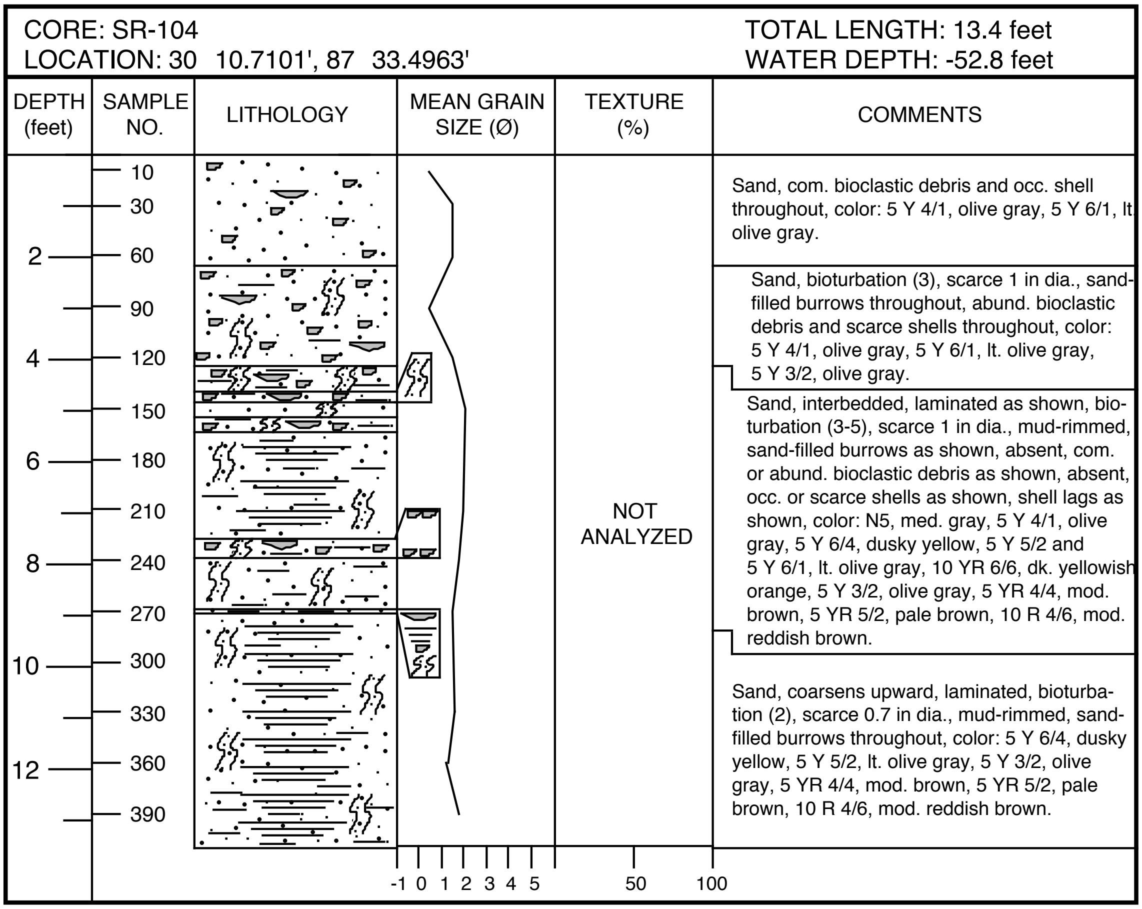
A-78.--Columnar section of EEZ vibracore SR-101.



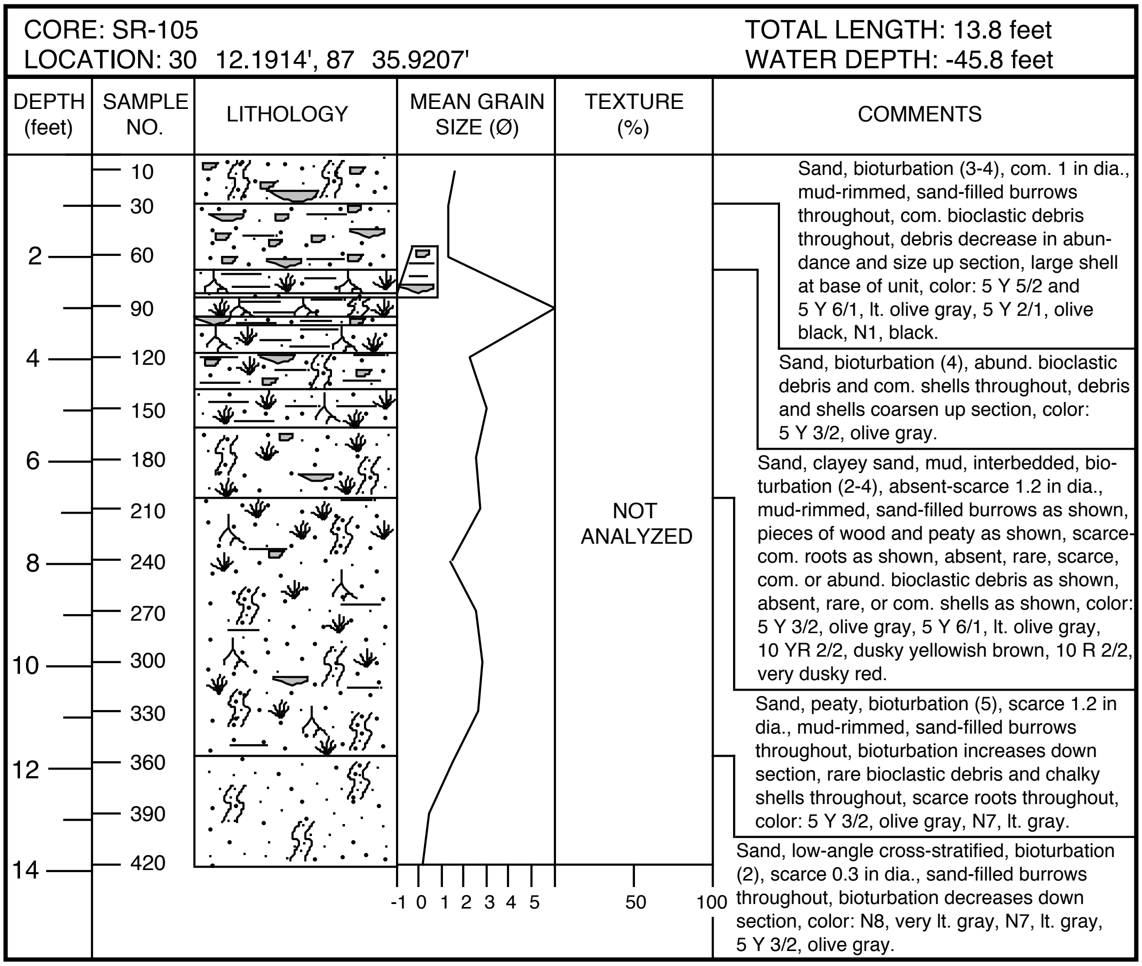
A-79.--Columnar section of EEZ vibracore SR-102.



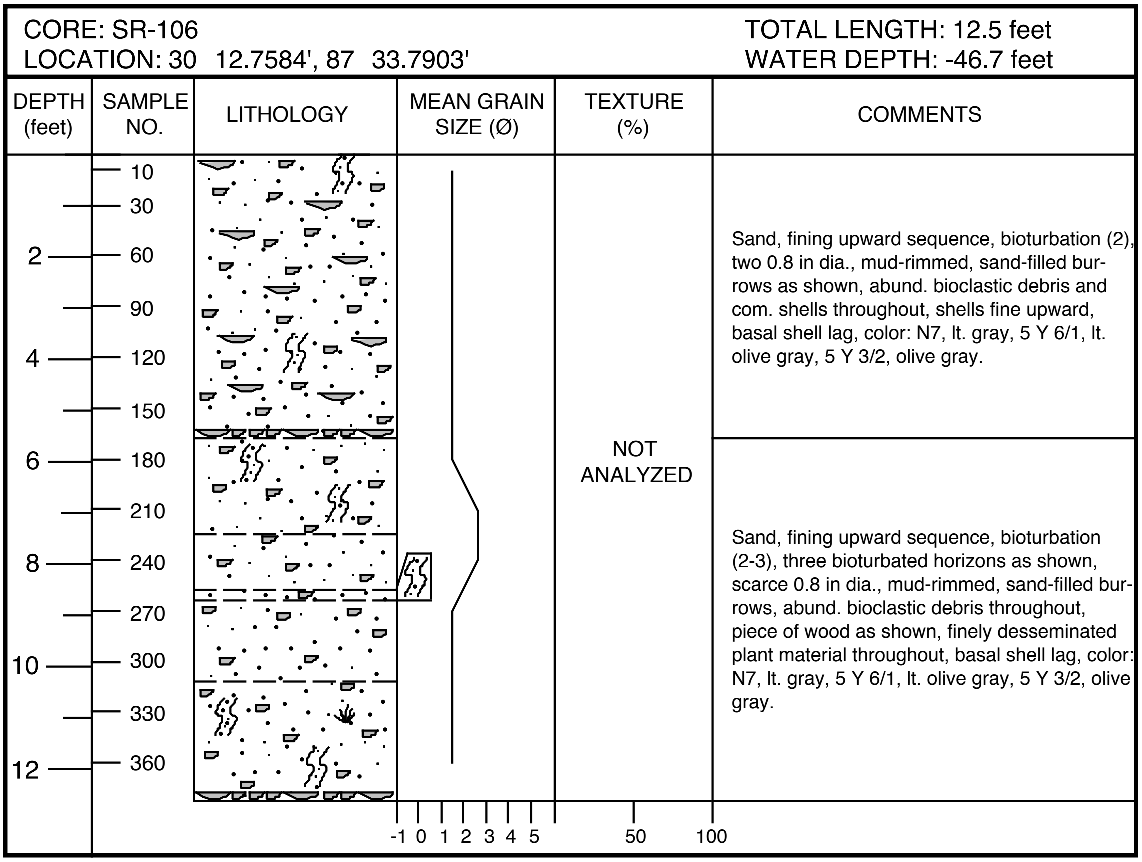
A-80.--Columnar section of EEZ vibracore SR-103.



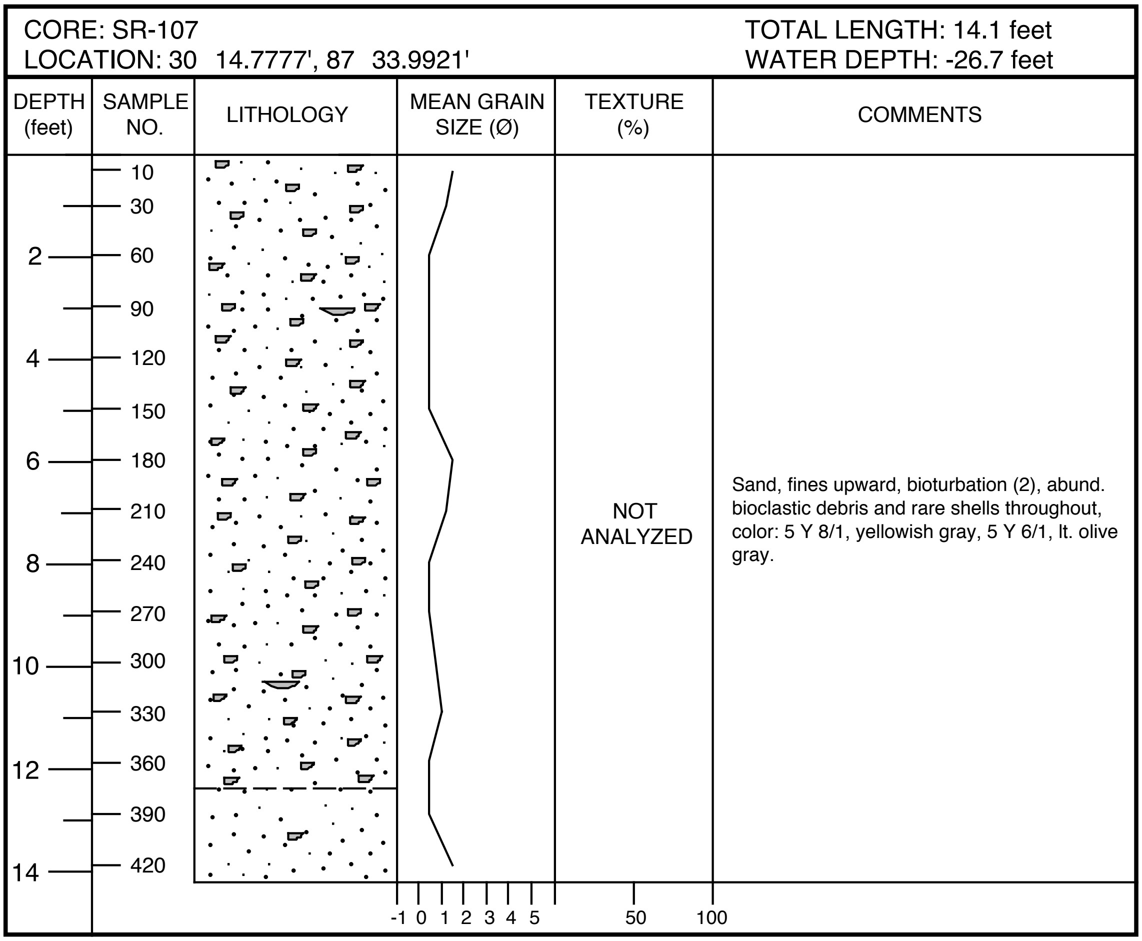
A-81.--Columnar section of EEZ vibracore SR-104.



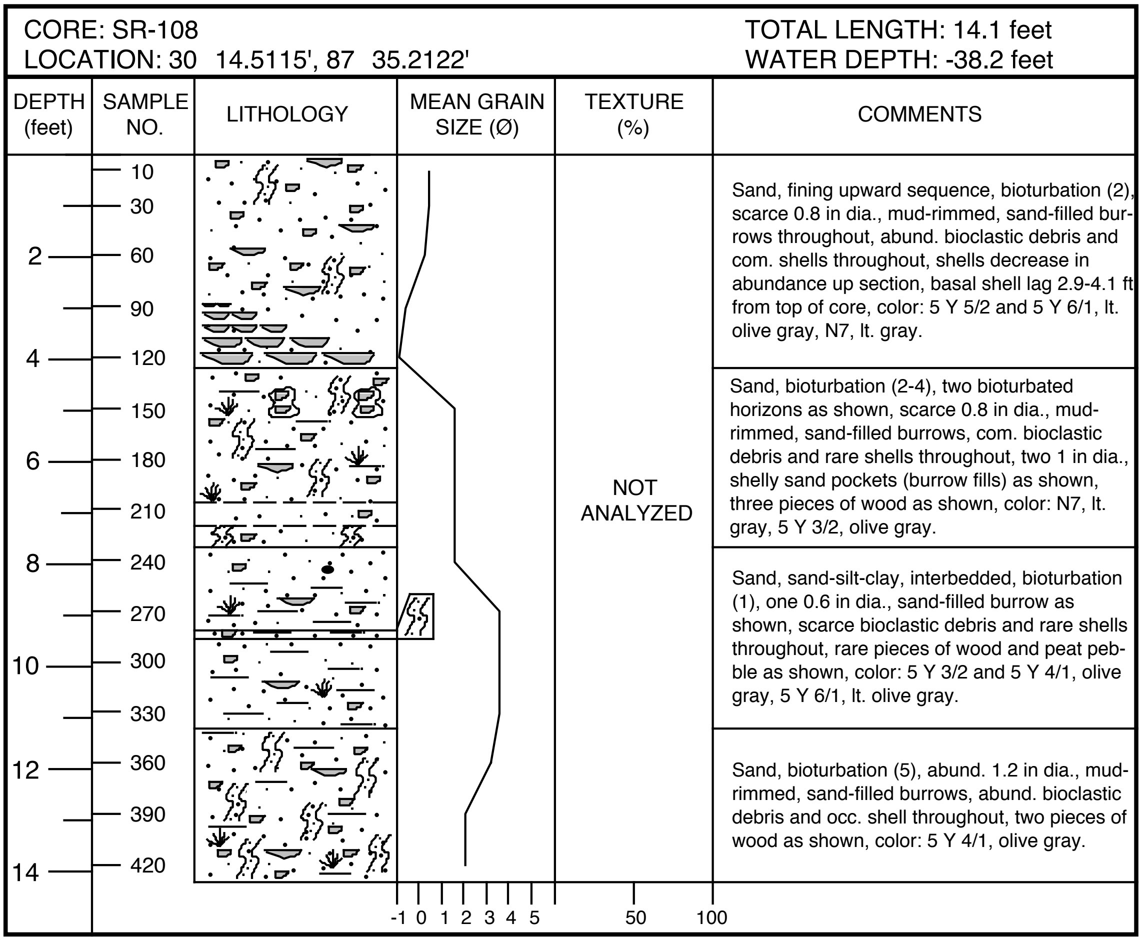
A-82.--Columnar section of EEZ vibracore SR-105.



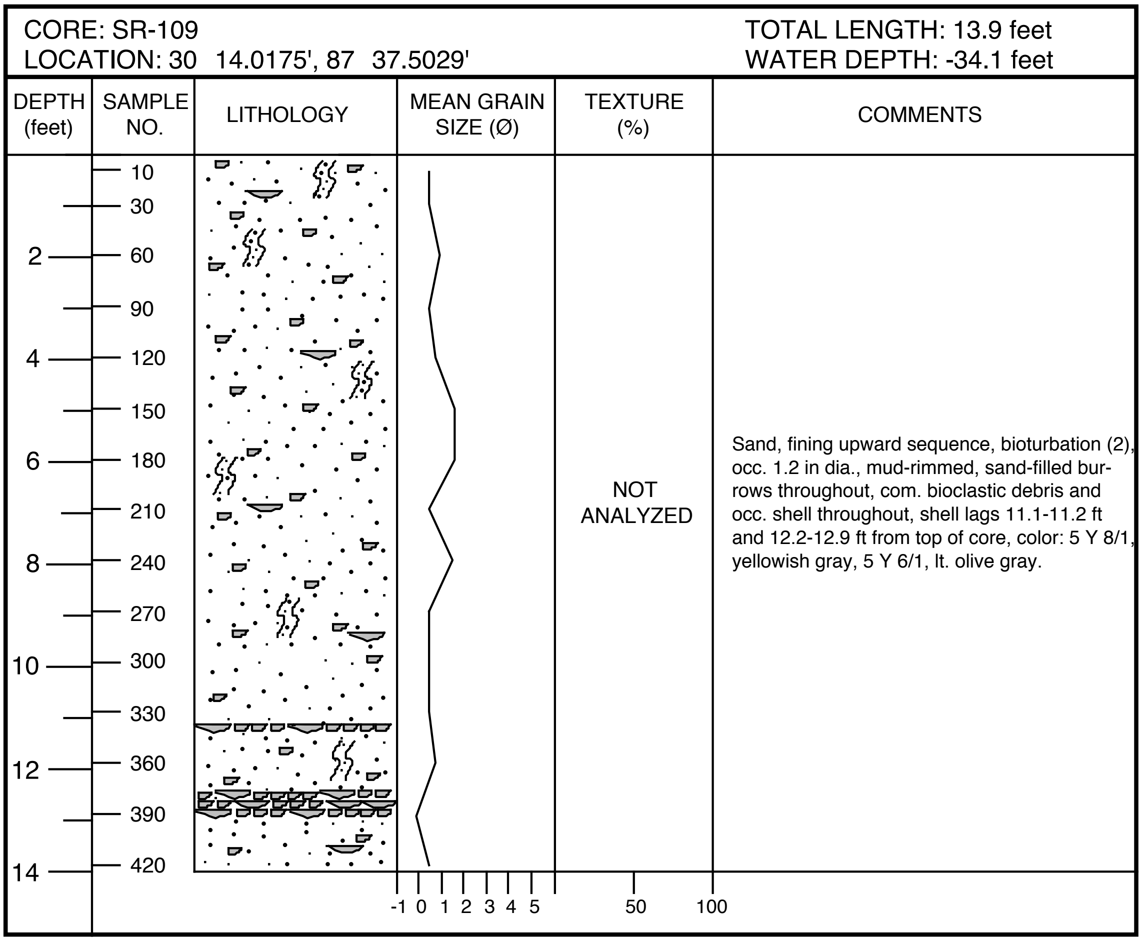
A-83.--Columnar section of EEZ vibracore SR-106.



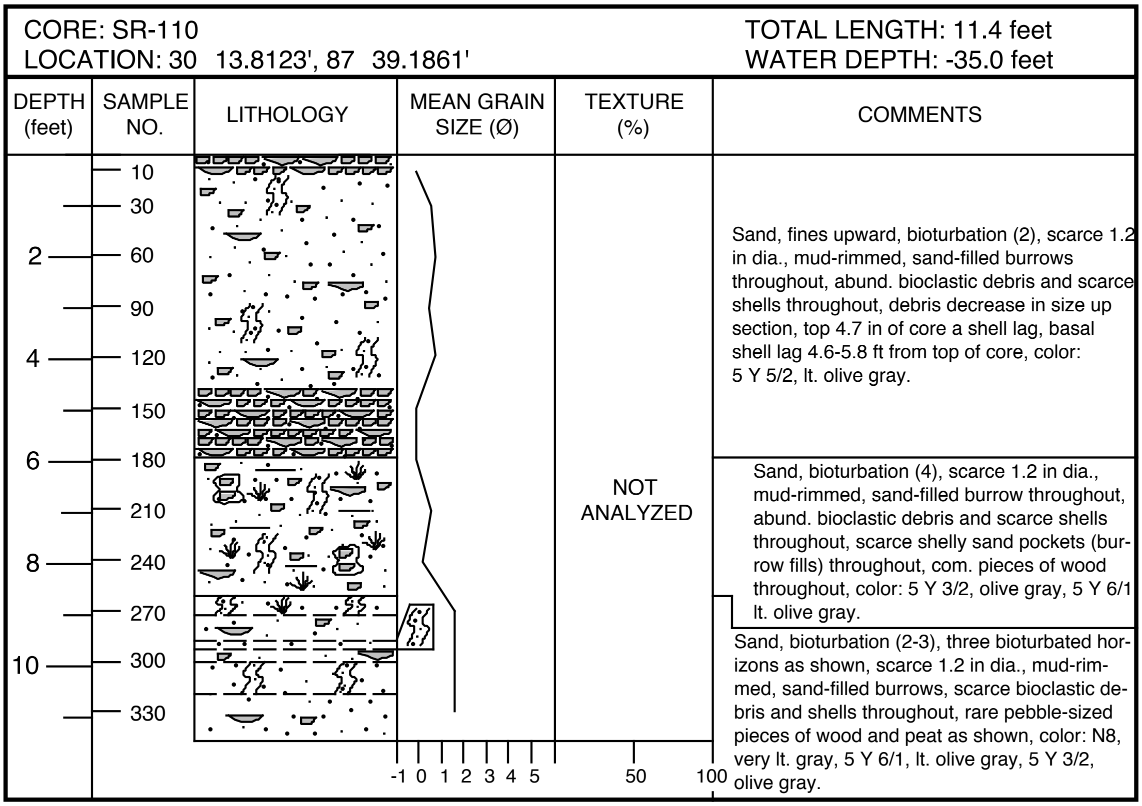
A-84.--Columnar section of EEZ vibracore SR-107.



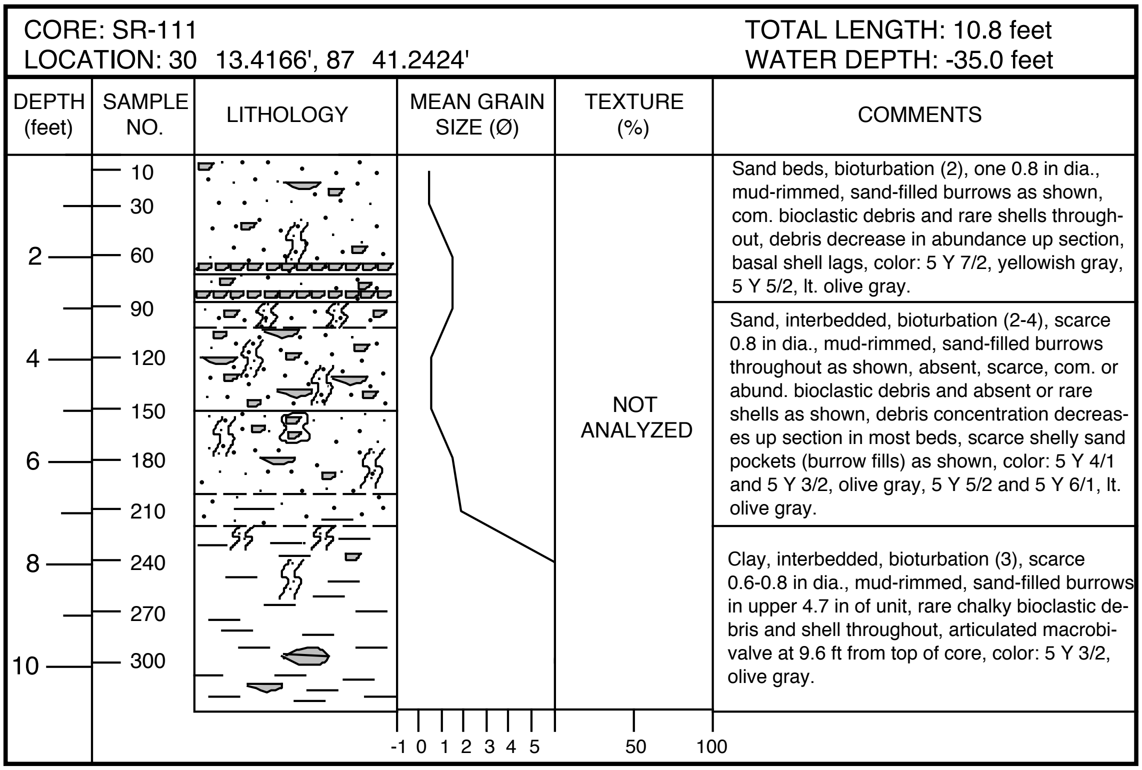
A-85.--Columnar section of EEZ vibracore SR-108.



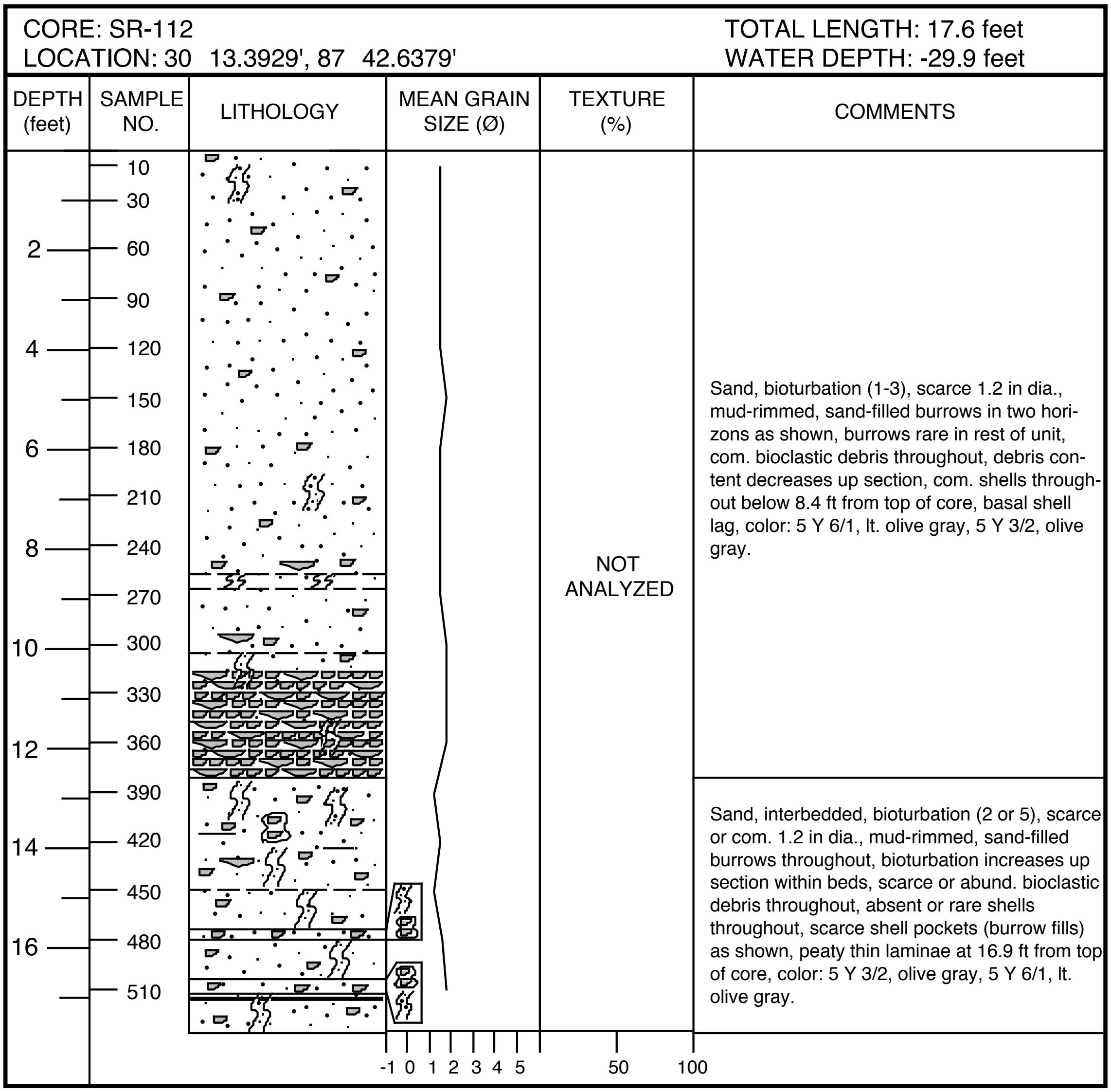
A-86.--Columnar section of EEZ vibracore SR-109.



A-87.--Columnar section of EEZ vibracore SR-110.



A-88.--Columnar section of EEZ vibracore SR-111.

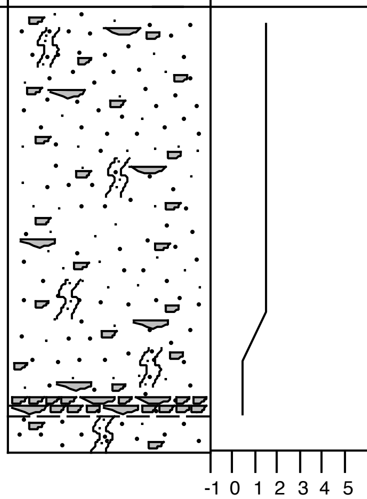


A-89.--Columnar section of EEZ vibracore SR-112.

CORE: SR-113
LOCATION: 30   12.5799', 87   43.1843'

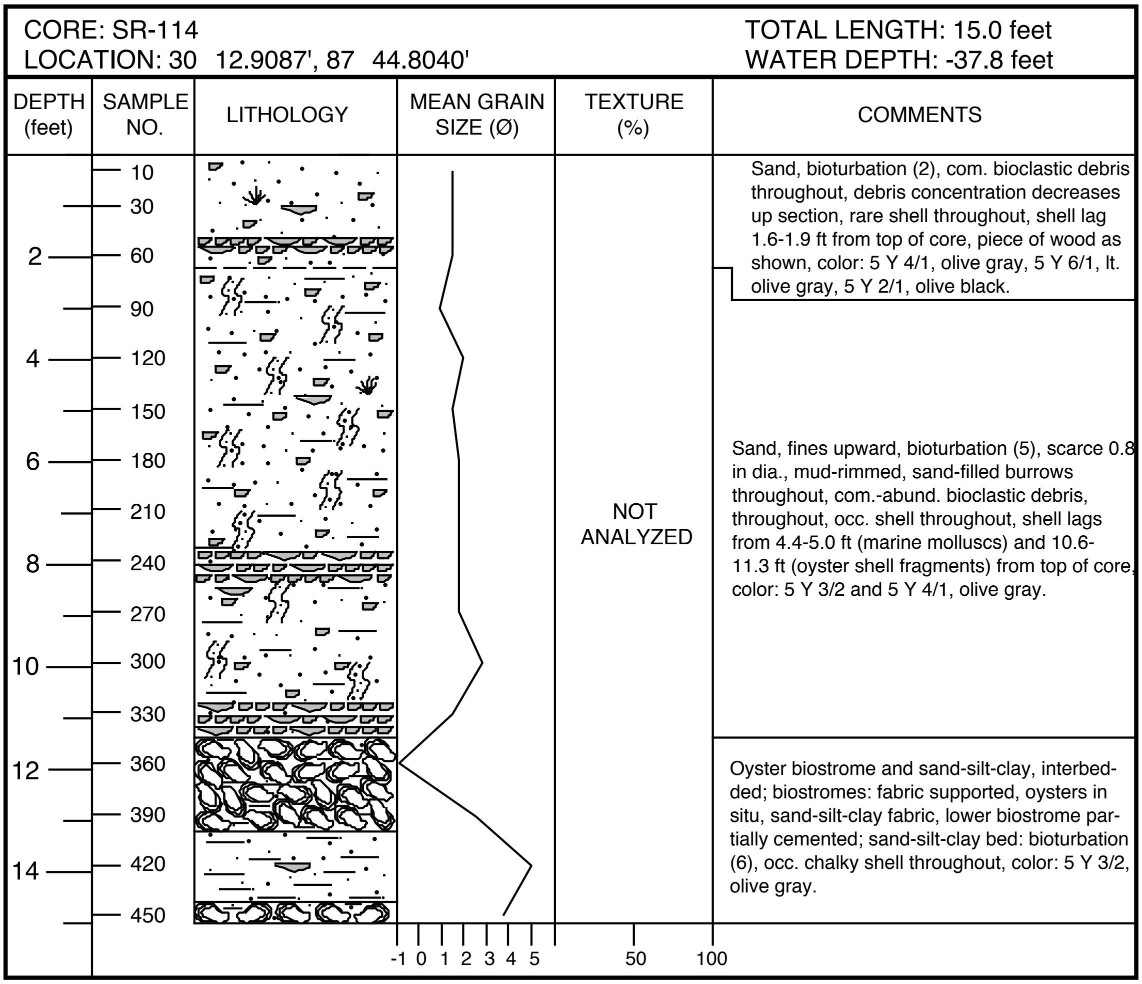
TOTAL LENGTH: 8.6 feet
WATER DEPTH: -32.9 feet

DEPTH (feet)	SAMPLE NO.	LITHOLOGY	MEAN GRAIN SIZE (Ø)	TEXTURE (%)	COMMENTS
	10				
	30				
2	60				
	90				
4	120			NOT ANALYZED	Sand, interbedded, bioturbation (2), scarce 1 in dia., sand-filled burrows throughout, bioturbation increases down section within beds, com. to abund. bioclastic debris throughout, scarce shells down to 7.9 ft below top of core, debris and shells decrease in concentration up section within beds, shell lag from 7.7-7.9 ft below top of core, color: 5 Y 7/2, yellowish gray, 5 Y 6/1, lt. olive gray, 5 Y 3/2, olive gray.
	150				
6	180				
	210				
8	240				

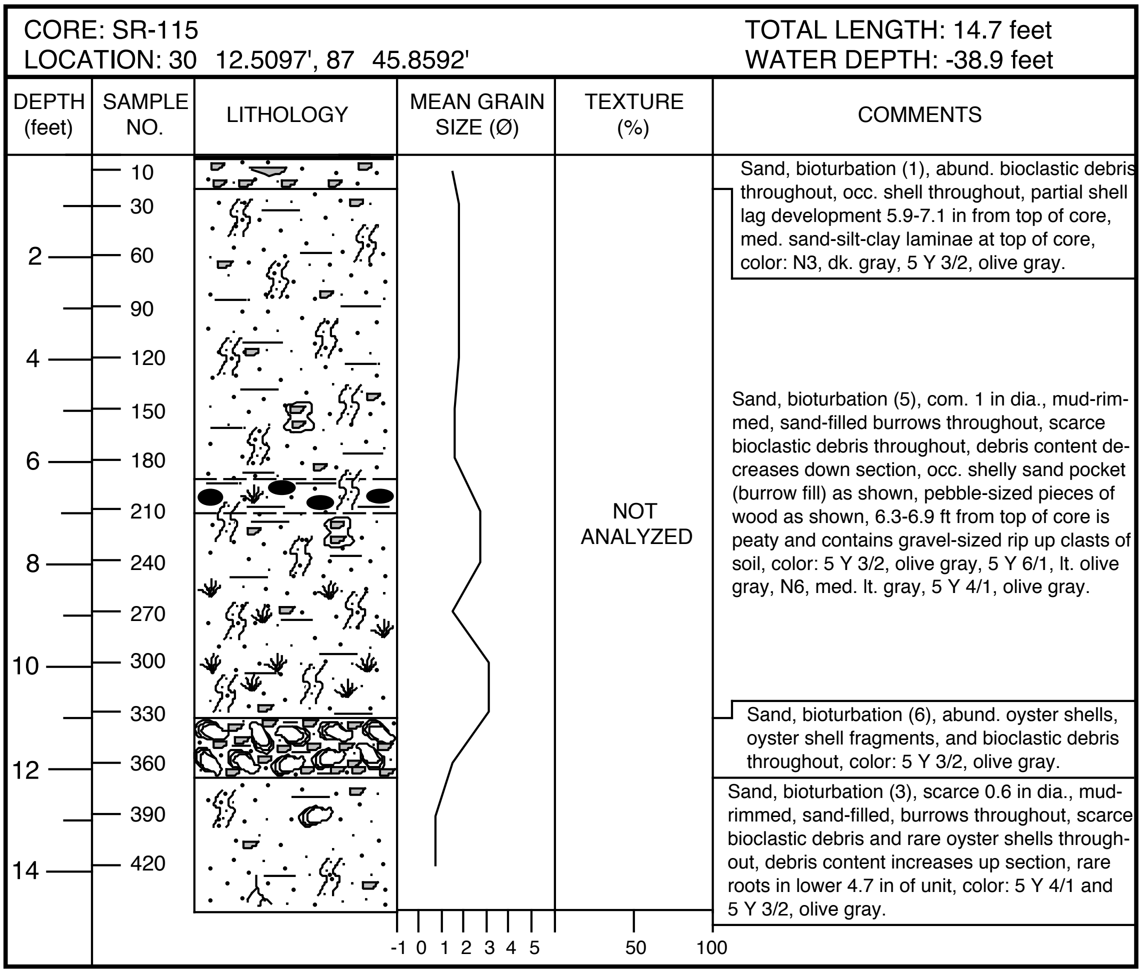


50 100

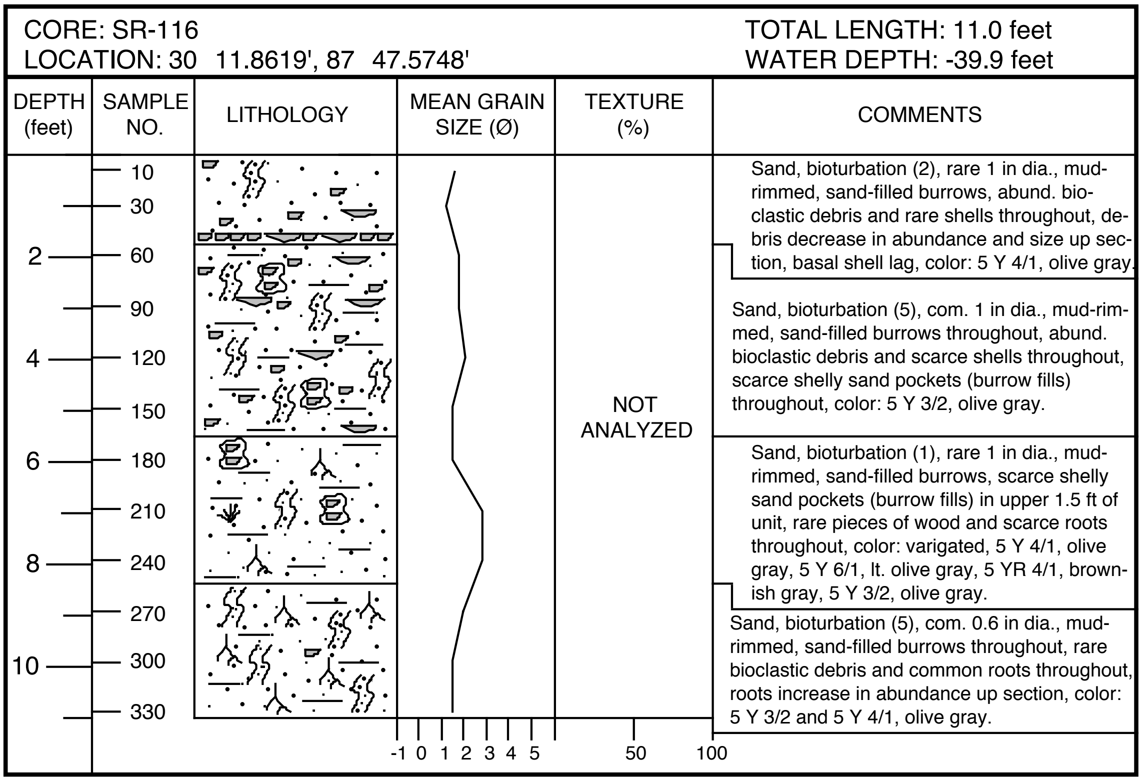
A-90.--Columnar section of EEZ vibracore SR-113.



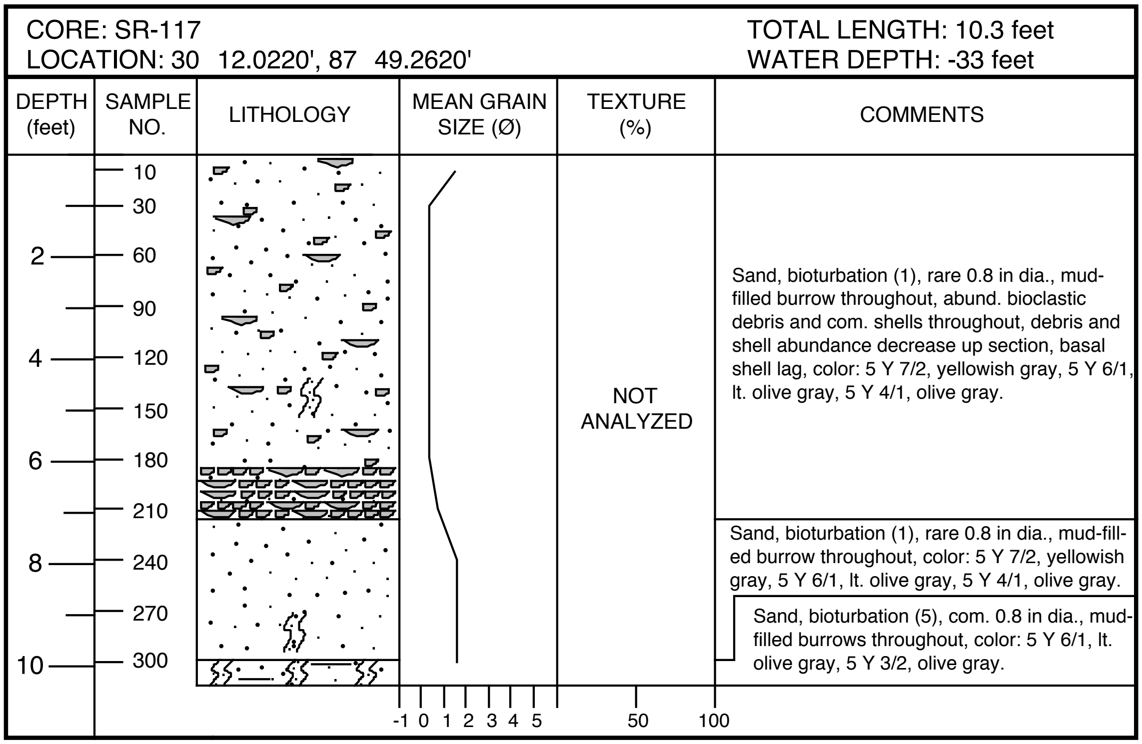
A-91.--Columnar section of EEZ vibracore SR-114.



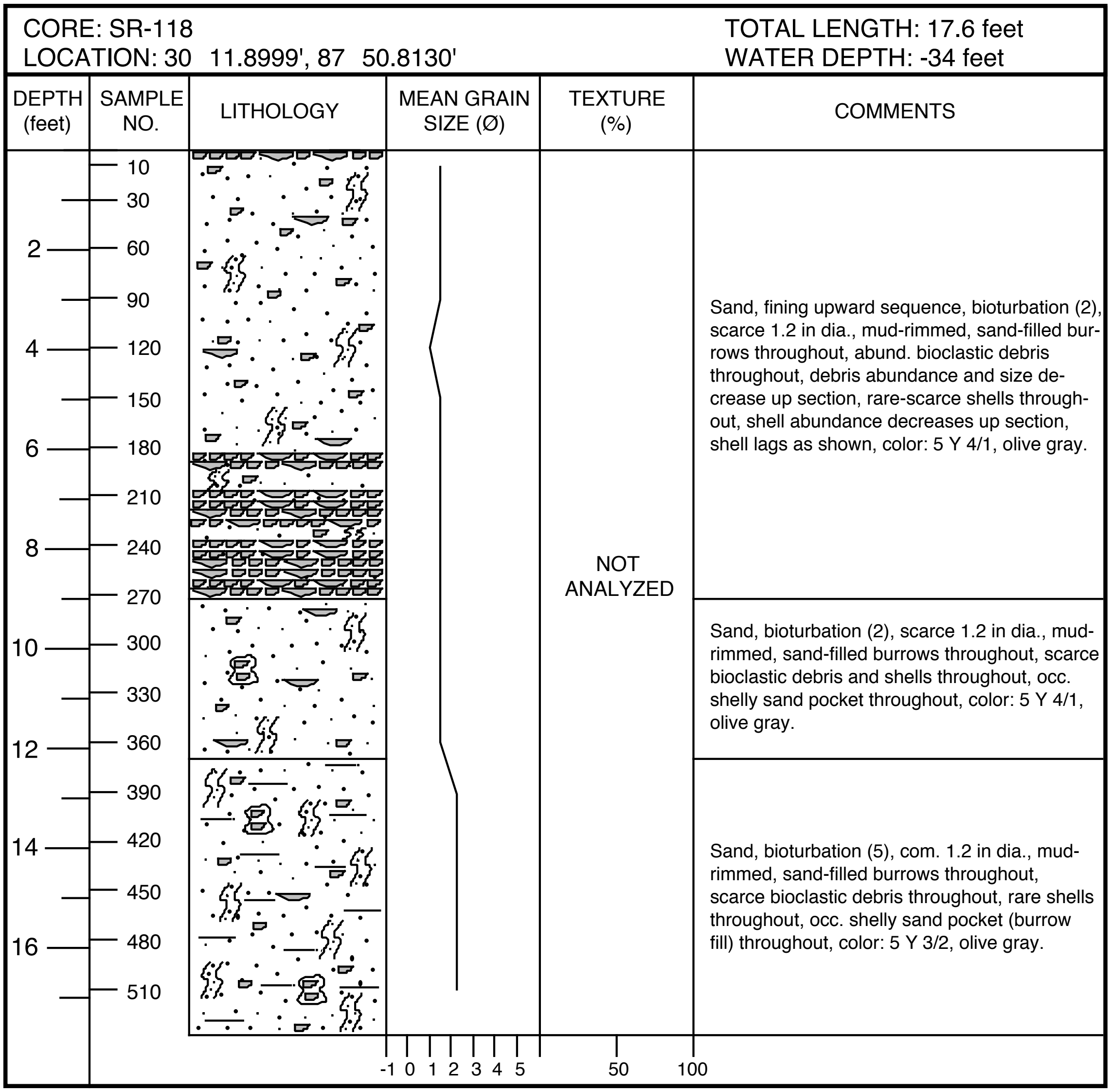
A-92.--Columnar section of EEZ vibracore SR-115.



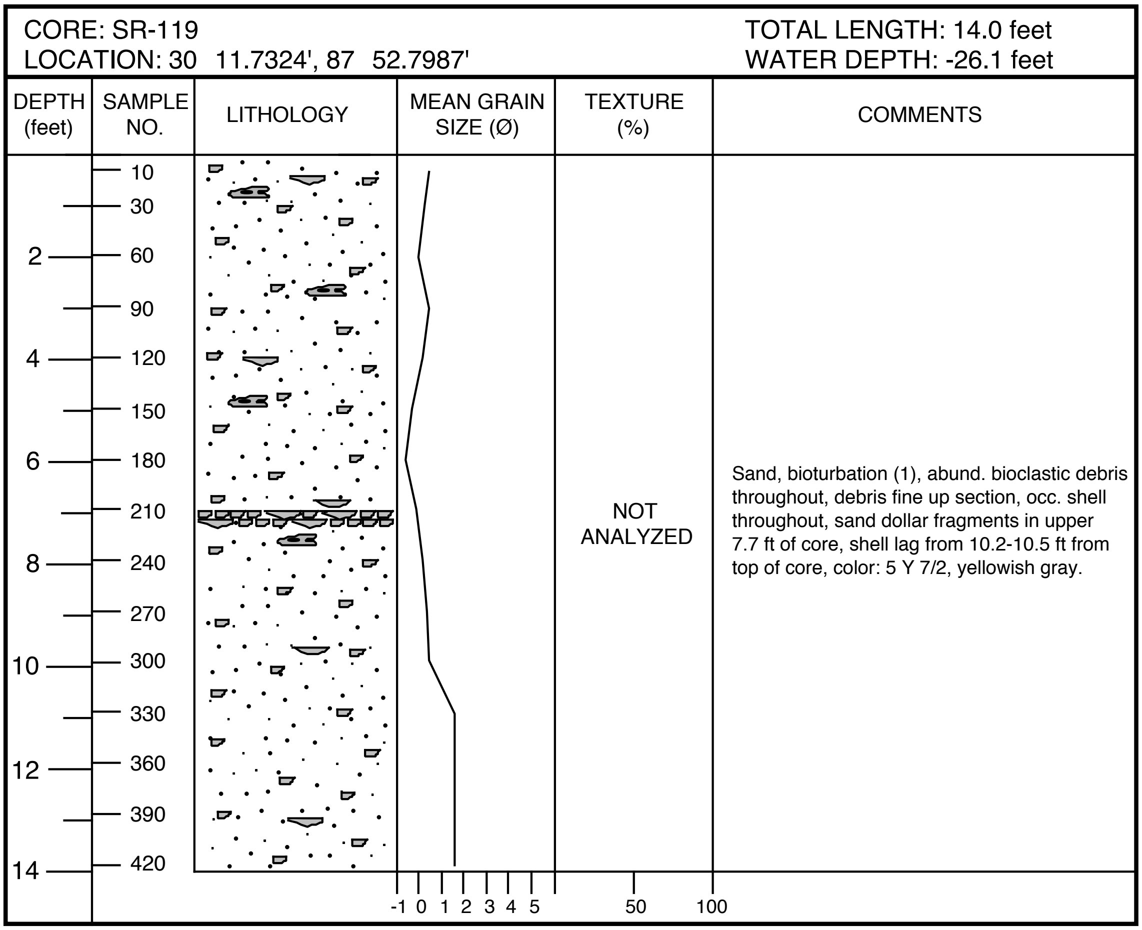
A-93.--Columnar section of EEZ vibracore SR-116.



A-94.--Columnar section of EEZ vibracore SR-117.



A-95.--Columnar section of EEZ vibracore SR-118.



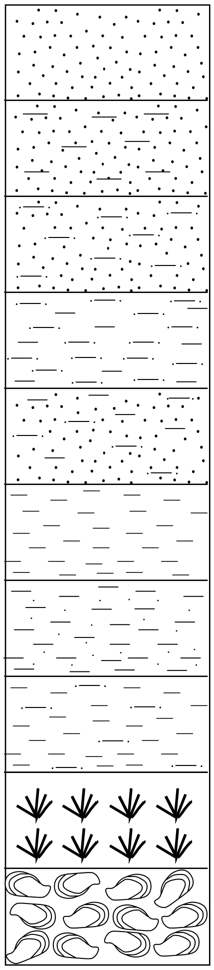
A-96.--Columnar section of EEZ vibracore SR-119.

APPENDIX B

EXPLANATION OF PATTERNS AND SYMBOLS

EXPLANATION OF PATTERNS AND SYMBOLS

SEDIMENT TYPES



SAND

CLAYEY SAND

SILTY SAND

CLAYEY SILT

SAND-SILT-CLAY

CLAY

SANDY CLAY

SILTY CLAY

PEAT

OYSTER BIOSTROME

ACCESSORIES

OYSTER SHELL

ARTICULATED PELCYPOD

INARTICULATED PELCYPOD

SHELL FRAGMENT

PEBBLE

GRANULE

NODULE

PEAT BALL

ROOTS

ORGANIC MATTER

CRAB

SEDIMENTARY STRUCTURES

SAND POCKET

CLAY POCKET

CLAYEY SAND POCKET

SANDY CLAY POCKET

MUD BURROW

SAND BURROW

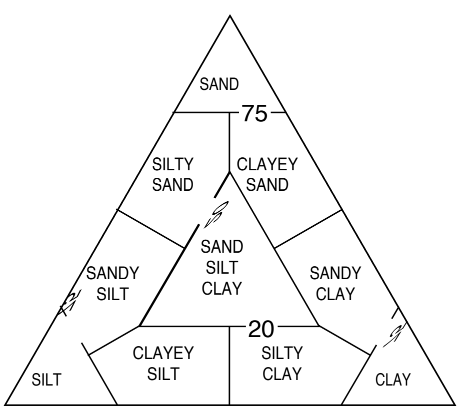
CLAY DRAPE

SAMPLE INDEX

310 - SEDIMENT SAMPLE

300 - C-14 SAMPLE

SEDIMENT TEXTURE NOMENCLATURE



BIOTURBATION INDEX*

(1) No bioturbation recorded; all original sedimentary structures preserved.
(2) Discrete, isolated trace fossils; up to 10% of original bedding disturbed.
(3) Approximately 10 to 40% of original bedding disturbed. Burrows are generally isolated, but locally overlap.
(4) Last vestiges of bedding discernable; approximately 40 to 60% disturbed. Burrows overlap and are not always well defined.
(5) Bedding is completely disturbed, but burrows are still discrete in places and the fabric is not mixed.
(6) Bedding is nearly or totally homogenized.

*(Droser and Bottjer, 1986)